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TELECOMMUNICATIONS INTERNETWORKING AND INTEGRATION: A PRIMER FOR C3 STUDENTS

by

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This thesis is a telecommunications internetworking and integration tutorial for command, control, and communications (C3) students, and is intended to supplement coursework material at the Naval Postgraduate School (NPS). It is particularly relevant to students pursuing the internetworking area of emphasis in the C3 curriculum. In order to recognize and tap the potential of internetworking and integration for military applications, C3 students must be "internetworking literate." The objective of this thesis is to help develop that literacy and to serve as a technical reference for understanding terms, standards and concepts associated with the complex field of telecommunications internetworking. As the ultimate Department of Defense (DoD) telecommunications goal is the full integration of voice, data and imagery services, internetworking is looked upon as an essential process on the road to integration. To establish the relevance to U.S. warfighting capability, this thesis describes how internetworking and integration are critical elements of the "C4I for the Warrior" initiative. With this warfighting connection kept in mind, definitions and illustrations present the technical aspects of telecommunications internetworking and integration.

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Telecommunications Internetworking and Integration: A Primer for C3 Students

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ABSTRACT

This thesis is a telecommunications internetworking and integration tutorial for command, control, and communications (C3) students, and is intended to supplement coursework material at the Naval Postgraduate School (NPS). It is particularly relevant to students pursuing the internetworking area of emphasis in the C3 curriculum. In order to recognize and tap the potential of internetworking and integration for military applications, C3 students must be "internetworking literate." The objective of this thesis is to help develop that literacy and to serve as a technical reference for understanding terms, standards and concepts associated with the complex field of telecommunications internetworking. As the ultimate Department of Defense (DoD) telecommunications goal is the full integration of voice, data and imagery services, internetworking is looked upon as an essential process on the road to integration. To establish the relevance to U.S. warfighting capability, this thesis describes how internetworking and integration are critical elements of the "C4I for the Warrior" initiative. With this warfighting connection kept in mind, definitions and illustrations present the technical aspects of telecommunications internetworking and integration.

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I. INTRODUCTION

A. PURPOSE

This thesis illustrates the key features of telecommunications internetworking and integration for individuals studying command, control and communications (C3). Telecommunications internetworking is becoming an increasingly important topic in the study of C3, as is the development of fully integrated digital telecommunications networks. This thesis provides an introduction to the complex field of internetworking, which is an essential step on the road to integrated digital networks.

As the telecommunications internetworking and integration fields are so broad, the objective is to provide the reader with a "broad brush" sketch of networking types, internetworking techniques, and integration possibilities. Additionally, this thesis is meant to provide an initial reference and guide to aid in searching for additional information.

B. ORGANIZATION

The approach taken in this thesis is to initially establish the relevance of telecommunications advancements to the warfighting environment. This is done in Chapter II, which presents a discussion of the command, control, communications, computers and intelligence (C4I) for the

Warrior initiative, and proposes that telecommunications internetworking and integration are both driving such initiatives and contributing to their success.

Chapter III then presents a general overview of telecommunications networks and definitions of terms. The discussion of protocols and standards in Chapter IV sets the stage for the more technical material of Chapters V and VI. Chapter V examines switching and transmission techniques, which are two major elements in any network. Chapter VI looks at local, metropolitan, and wide area networks (LAN, MAN, and WAN). This chapter also describes and illustrates some of the internetworking methods and the devices which enable network interconnections to take place. By way of illustration, some network applications with which the reader may be familiar are presented. Chapter VII looks at some of the current implementations of telecommunications internetworking techniques, and describes the trend toward digital integrated networks.

To understand how to make initiatives such as C4I for the Warrior a reality, C3 professionals need to have a solid grasp of telecommunications internetworking and integration principles. The contributions of internetworking methods to interoperability and C4I system integration are central themes of this thesis. By keeping these themes in mind, the technical material of the thesis can be viewed from the proper perspective.

II. THE WARFIGHTING CONNECTION

This chapter establishes the importance of telecommunications internetworking and integration for joint U.S. military operations. A central theme of this thesis is that telecommunications internetworking and integration play a key role in both the development and implementation of U.S. military options. The material presented in this chapter reinforces this idea, justifying the need for joint C3 students to become thoroughly familiar with telecommunications internetworking and integration equipment and techniques.

A. BACKGROUND

Throughout the history of warfare, military strategies have been continually modified as a result of global and regional power shifts. With a new era in international relations now unfolding, the U.S. is carefully reevaluating its political and military objectives. The result is a departure from a policy of containing communism and deterring Soviet aggression to a more flexible, regionally oriented strategy capable of countering a wide range of potential threats. (Annex C,NMSD,FY94-99)

While the U.S. now faces a dramatically diminished likelihood of deliberate aggression, this threat has been replaced by the equally complex challenges of regional

crisis management and conflict prevention. There has been a fundamental shift in military priorities, accompanied by careful consideration of how to achieve newly defined goals.

To effectively meet the new challenges, decision makers and warfighters require the ability to rapidly access and process vast amounts of information. This thesis proposes that for mission success, they need to be able to send "anything, anytime, anywhere." To send "anything" requires a "pipeline" with adequate capacity and speed. To send it "anytime" requires real-time[1] accessibility, and to send it "anywhere" requires the ability to interconnect with other networks around the world. (Johnson,1990,p.152)

Fortunately, the U.S. faces the new challenges with high-technology systems never before available, thanks to technological advances no less dramatic than the changes in the international environment. Particularly remarkable have been advances in the technology associated with telecommunications internetworking and integration. As a result, modern telecommunications systems are now able to provide political and military leaders with timely access to enormous amounts of information upon which to formulate warfighting strategies and implement flexible response options.

[1]Real-time generally means arriving when you need it, or at the time you expect it; not necessarily immediately, or even particularly fast.

This chapter introduces the relationship between new U.S. military strategy implementation and emerging telecommunications internetworking and integration capabilities. The existence of this relationship or "connection" justifies the careful study of these new capabilities by military C3 professionals. The implementation of flexible-response options will demand more speed, greater bandwidths, and integration of voice, data and image on a single medium. (Annex C,NMSD,FY94-99) New techniques and emerging equipment are evolving to support that demand, if recognized and used to their full potential.

B. RESPONSIVE OPTIONS AND NEW TECHNOLOGIES

To support the regional contingency focus and the key foundations of the new strategy more efficiently and effectively, the Chairman of the Joint Chiefs of Staff (JCS) has provided the defense planning guidance which requires the following capability objectives:(J-6 Concept Paper,1992)

- strengthening joint and combined forces C4I interoperability
- acquiring C4I adaptability
- capitalizing on advancing technologies

It is through an examination of these capabilities that one immediately recognizes the relevance of telecommunications internetworking and integration capabilities to newly defined objectives.

Telecommunications internetworking has become a vital element at all levels of the command structure, with astounding implications for force enhancement and cost savings. To capitalize on this potential, C3 professionals must understand both how internetworking expands military options and how to evaluate the technical, organizational and economic tradeoffs in implementing networks. (Johnson,1990,p.152)

The increased emphasis on joint and combined operations logically leads to a heightened awareness of the benefits of interoperability and integration. Though long given "lip service" for their virtues, these concepts had previously not been put into widespread use due to service loyalties and other factors. Consolidating redundant functions, increasing overall system throughput, and merging existing "stovepipe" systems to achieve interoperability will assist in the development of a streamlined "global infrastructure" that reduces overall costs and provides more efficient use of scarce resources. The command and control of U.S. forces in worldwide contingency operations can no longer rely on the ad hoc assembly of service-unique systems. Joint and combined interoperability is essential for establishing integrated systems, for connecting deployed systems to a global infrastructure, and for establishing a Department of Defense (DoD)-wide architecture that integrates functions and transfers information between different commands and

agencies. Because existing C4I systems, procedures, and information requirements are very different among the service components at echelons below the theater or regional commander, it will be necessary to use interconnection equipment to compensate for these differences and make our existing systems work together to achieve interoperability. This will be more affordable than wholesale replacement of C4I systems in achieving effective joint interoperability in the near term. (Signal,June 1992,pp.91-93) Once again, it is easy to see how those involved with the technical aspects of achieving this system interoperability will require an understanding of the telecommunications internetworking fundamentals and integration goals presented in this thesis.

Technical interoperability provides the means for exchanging information among systems and users so that each can receive and understand the contents--an essential element for joint forces to operate in an integrated manner. It is achieved through common standards, designed into systems and equipment. The standards needed for joint and combined interoperability cover a wide range of mission needs. Some elements of these standards already exist and are being widely implemented, but greater use of open systems standards approved by national or international bodies is required. Chapter IV of this thesis explains these standards and provides insights into current and future compliance.

Increasingly, interoperability with commercial systems will be required in order to augment military systems during contingencies, provide robust command and control, and reduce acquisition costs and lead times to field new systems (Annex C,NMSD,FY94-99). Accordingly, this thesis discusses some aspects of commercial-off-the-shelf (COTS) equipment, which can often be readily adapted for military use.

C. C4I FOR THE WARRIOR

Blending the two evolutionary processes of capability objectives and technology is the concept of C4I for the Warrior (CFTW). This concept takes advantage of new technologies, while striving to assimilate it into definitions of new U.S. objectives. (Signal, June 1992, pp.94-96)

While CFTW will undoubtedly see much revision, and the name itself may change, the groundwork it establishes will endure. The CFTW vision sets forth a concept--a unifying theme--guiding principles and a roadmap for achieving global C4I joint interoperability. As currently defined in a J-6 CFTW concept paper, the roadmap to completion includes: (CFTW,J-6 Concept Paper,1992)

- A Quick Fix Phase that will achieve interoperability between existing C4I systems by use of translators, adherence to a common set of joint standards, rigorous testing for conformance, and configuration management enforcement.

- A Mid-Term Phase that achieves total interoperability for new C4I systems during development, testing, acquisition, and implementation and establishes a joint wide-area network based on digital commonality.

- An enduring Objective Phase during which evolving technologies and techniques are continuously identified and assimilated and a fully developed C4I network of fused information, updated automatically, is available from which the joint warfighter can pull information.

Quick fixes include the installation of translation devices that interpret nonstandard message and data formats and protocols and produce common outputs that can be readily exchanged via standard transmission paths. It is during this short-term phase that the technical internetworking material presented in this thesis has the most readily apparent value. The capabilities of telecommunications internetworking and integration are by nature geared toward enabling communication between previously non-compatible sources. This phase offers the most immediate payoff in a fast-moving industry.

The Mid-term Phase produces a global C4I system capable of generating and delivering the fused information needed for tactical command decisions. The Mid-Term Phase is concurrent with the Quick Fix Phase and encompasses the Program Objective Memorandum (POM) period plus the following ten years. During this period the following is expected to be accomplished: (CFTW,J-6 Concept Paper,1992)

- Interoperability becomes fully integrated into the policy, doctrine, and system acquisition processes for all new C4I systems and modernization programs.

- Modular building blocks are described in technical detail.

- A common network operating environment cements the modular building blocks into a joint network of networks.

- Applications interoperability and standardization produce fixed, transportable, and tactical communications and information nodes that are interconnected in support of joint or combined operations irrespective of time, place, or Service/Agency sponsorship.

- The joint global C4I infrastructure evolves toward a single common, unified, interoperable system.

- Migration from unique military standards to commercial national and international standards.

The Objective Phase extends beyond the year 2000 and is very dependent upon advanced technology drivers. Necessary progress is expected in at least the following areas:

- Artificial intelligence applications.

- Multilevel security.

- Data compression and data fusion.

- Common operating and interface environments.

The developers of the CFTW initiative feel that the greatest payoffs are possible by careful planning now for this long-term phase. Although it is difficult to predict how the technological landscape will look in the future, the framework needs to be established which will ensure that evolving technologies are recognized and applied.

The joint commanders' C4I capability will have to integrate C4I across the force and connect to the global infrastructure and theater and regional command elements as

necessary. New methods for networking, multilevel security, data compression, and very high speed information processing systems can further enhance the ability of C4I systems to support the commanders' decision-making process, using a consolidated "seamless" global information network.

In the long term, the new architecture will require that future systems be built from modules rather than as separate monolithic system elements. These modules will be "plugged together" to establish an integrated, seamless, global joint system that is capable of efficiently supporting forward-presence and crisis response operations of any size, intensity, and duration.

The global infrastructure under the proposed new architecture will be comprised of backbone communications, facilities, gateways, and information processing systems for joint commands. The CFTW initiative envisions using commercial networks and commercial standards as key considerations for the objective concept.
(FACRP Report,1992)

The CFTW initiative provides the capstone requirements and road map for evolving to an integrated, interoperable global command and control infrastructure. The CFTW initiative wouldn't be possible without today's internetworking capabilities, and the thread that will run throughout this thesis is how these capabilities contribute to the successful implementation of this DoD-wide

initiative. That is what defines the importance of telecommunications internetworking and integration to joint C3 students, as future communicators, planners or operations staff members in unpredictable warfighting environments.

With the warfighting connection kept in mind, this thesis presents telecommunications internetworking fundamentals and integration goals, and provides insights into opportunities for military applications.

III. TELECOMMUNICATIONS NETWORKS AND INTEGRATION GOALS

This chapter introduces the internetworking and integration equipment and methods which have sparked initiatives such as C4I for the Warrior and defined their expectations. Telecommunications internetworking and integration are extremely broad and rapidly evolving fields, with technical capabilities advancing at a phenomenal rate. The evolutionary technological advances are permeating the defense establishment, and innovative military applications are possible if recognized and acted upon. To fully comprehend the potential military applications of telecommunications internetworking and integration requires an understanding of key networking concepts and terms. Equipped with this basic understanding, one can begin to appreciate what constitutes a network and how it is structured. A more in-depth technical examination of existing and emerging equipment and industry standards can then follow. Accordingly, this chapter provides several introductory definitions. This introduction to terms will help prepare the reader for the more technical material presented in subsequent chapters.

Following a traditional approach, voice, data and video networks are briefly described in this chapter to provide an overall "flavor" of networks. As the movement toward

digital integrated services is very important in the new military environment, this chapter then introduces the idea of integration of voice, data, and video services within the network. Chapter VI will provide the internetworking details on how these networks can be made to interact with each other, both through interconnection devices and consolidation into fully integrated digital wide area networks.

A. DEFINITIONS

In the language of telecommunications there are unfortunately various definitions of the same commonly used terms. This section clarifies the meaning of several terms and phrases as used in this thesis. The introductory definitions provided here will familiarize the reader with some of the more commonly used networking terms.

- *Telecommunications* entails disciplines, means, and methodologies to communicate over distances; in effect, to transmit voice, video, facsimile and computer data.

- *Data communications* entails disciplines, means, and methodologies particular to transmission of computer data, possibly over a specially engineered network; a subset of the telecommunications field.

- *Networks* are interconnections of systems which include computers, terminals, and communications facilities. A detailed discussion of networks is provided in Chapter VI.

- *Internetworking* implies the capability of different networks to interact with each other.

- *Integration* implies integration of voice, data and video on a single network, with a universal network interface.

- *Layers* are defined sets of related communications functions.

- *Protocols* are sets of rules for how information is exchanged over a network. Protocols can cover the complete network interface or be limited to one or more of the layers out of which the network is constructed.

- *Standards* are publicly agreed protocols.

- *Local Area Networks (LAN)* are networking connections between multiple computers intended to allow the individual stations to share resources and exchange files; networks used at a single office, building, or group of buildings employing direct connections, rather than a common carrier or private communications system.

- *Metropolitan Area Networks (MAN)* are standardized, high-speed networking connections providing LAN-to-LAN and LAN-to-WAN connections for public or private communications systems within metropolitan-range distances.

- *Wide Area Networks (WAN)* are networking connections for transmission over long distances, often using existing public network facilities.

- *Topologies* denote the arrangement of pathways, and therefore the flow of information on a network; the structure, consisting of paths and switches, that provides the communications interconnection among users of a network.

- *Repeaters* are devices that retime and reamplify the signal received on one network segment before resending it on all other segments.

- *Bridges* are connection devices that link two networks that use identical protocols into a single logical network.

- *Routers* are connection devices that link two networks that are running different[2] protocols into an internetwork in which each network retains its logical identity as a separate network segment.

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[2]A router can also link identical protocols, as a bridge does.

- *Gateways* are internetworking devices designed to connect two or more dissimilar networks.

- *Switched Communication Networks* are communications networks consisting of a network of nodes connected by point-to-point links; data are transmitted from source to destination through intermediate nodes.

- *Multiplexing* is a function that permits two or more communications sources to share a common transmission medium such that each source has its own channel.

- *Modulator-demodulators (modems)* are devices that transform a digital bit stream into an analog signal (modulator) and vice versa (demodulator).

- *Open systems* are sets of one or more computers, the associated software, peripherals, terminals, and physical processes of which together are capable of performing information processing and/or information transfer; consists of modular, multi-vendor interoperable building blocks that are assembled into functional units.

- *Open Systems Interconnection (OSI) Reference Model (OSIRM)* refers to the seven major layers defined by the International Organization for Standardization (ISO). The OSIRM is discussed in Chapter IV.

- *Government OSI Protocol (GOSIP)* is government-sponsored, OSI-based specification intended to permit communication and interoperability of end-user and intermediate level systems throughout the government.

- *Stovepipe systems* are specialized systems which were designed to meet individual CINC and Services organizational structures and mission needs.

- *Standards and standards making bodies* are listed here, and are described in Chapter IV. The benefit of these organizations is their ability to develop robust, flexible, modular, and interoperable standards.

- *International Organization for Standardization (ISO)*

- *American National Standards Institute (ANSI)*

- *International Telegraph and Telephone Consultative Committee (CCITT)*

- *Institute of Electrical and Electronics Engineers (IEEE)*

- *Electronics Industries Association (EIA),* recently renamed the *Telecommunications Industries Association*

- *National Institute of Standards and Technology (NIST)*

- *North American Integrated Services Digital Network (ISDN) User's Forum (NIU-Forum)*

- *Defense Information Systems Agency (DISA)*

B. TRADITIONAL VIEW OF TELECOMMUNICATIONS NETWORKS

A traditional method of viewing networks has been to consider voice and data networks as distinct and different, and to study them separately. Similarly, video teleconferencing on private corporate networks and television on broadcast radio or cable networks were considered on their own.

The traditional public switched telephone network was designed to service voice traffic. Data can be carried by the same network when a modem (modulator-demodulator) is employed by users at each end of the link. The modem transforms the data to fit the nominal 4-kHz bandwidth of a standard telephone channel. The military environment, along with the rest of society, is becoming more informationally and visually oriented. Personal computing facilitates easy access, manipulation, storage, and exchange of information. These processes require reliable transmission of large amounts of data information. Communicating documents by images and the use of high resolution graphics terminals provide a more natural and informative mode of human interaction than just voice and data. (Griffiths,1992,p.31)

The traditional voice, data and video networks were largely engineered for a specific application and are ill-suited for other applications. For example, the traditional telephone network is too noisy and inefficient for bursty data communication. On the other hand, data networks which store and forward messages using computers have very limited connectivity, usually do not have sufficient bandwidth for digitized voice and video signals, and suffer from unacceptable delays for these real time signals. Television networks using the radio or the cable medium are largely broadcast networks with minimal switching facilities. High definition imagery means improved quality images at the expense of higher transmission bit-rates, which may require new transmission means other than the present overcrowded radio spectrum. (Hui,1990,p.62)

C. NETWORK INTEGRATION

It is often desirable to have a single inter-network for providing all the communication services discussed above in order to achieve the economy of sharing and to improve survivability and reliability. This motivates the general ideal of an integrated services network. Integration avoids the need for many overlaying networks, which complicate network management and reduce the flexibility in the introduction and evolution of services. This integration has only recently become possible with the advances in transmission, switching and multiplexing techniques.

Using the telephone company plant as an illustration, Figure 1 depicts the five-stage evolution to integrated networks. (Minoli,1991,p.32)

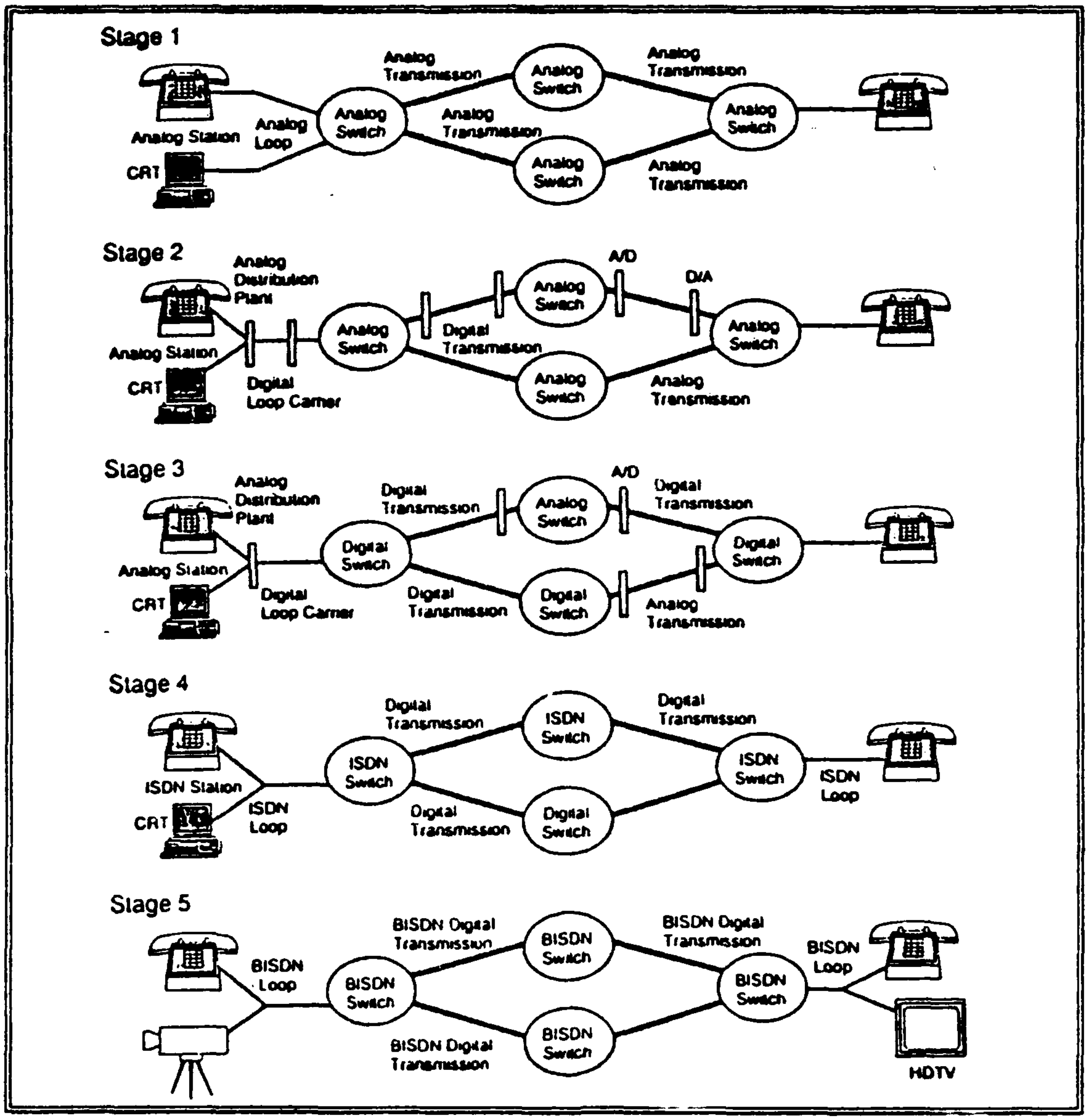

Figure 1.
Evolution of the Telephone Company Plant

Integration within the network can have different meanings, depending on the part and the function of the network being considered. (Hui,1990,p.12-13)

First, integrated access involves the sharing, among services from an end user, of a single interface to a single transmission medium in the local access network. A well integrated access network should provide flexible multiplexing of as many services as possible.

Second, integrated transport involves the flexible sharing, among services from possibly many users, of high capacity transmission links in the network. Integrated transport avoids the segregation of different traffic types and media onto different transmission links, hence may facilitate easier interactions between media within the network.

Third, integrated switching involves switching multi-rate, multi-media services within a single switching machine, in particular a single interconnection network. An integrated switch would avoid the necessity of adding a new interconnection network whenever a new service of distinct traffic characteristic is introduced. An integrated switching network must be flexible enough to meet the delay and bit-rate requirements of each service.

Fourth, integrated call processing involves the sharing of communication software for calls of different multi-media, multi-rate, and multi-point configurations.

Integrated call processing provides a uniform and flexible functional description of calls, and uses a single procedure to map the resource requirements of calls onto the available physical resources in the network. (Hui,1990,p.12-13)

A typical telecommunications network of the 1990s is depicted in Figure 2. (Minoli,1991,p.8)

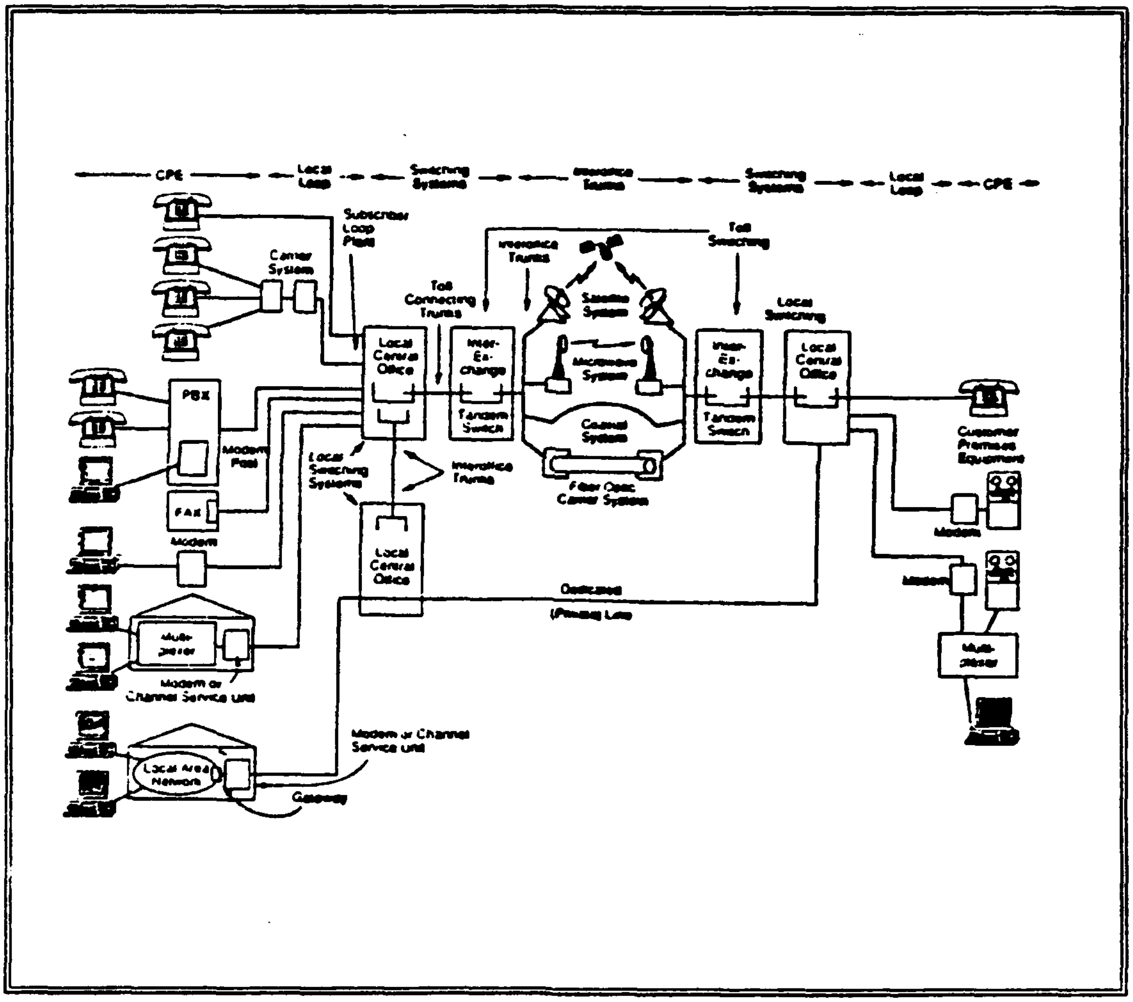

Figure 2
A Modern Telecommunications Network

Despite the advantages of integration, there are practical reasons why the process of integration can be slow and difficult in the public network or in a military network. Since the building and upgrading of a network is a slow process, the integration and upgrading ideally should be compatible with the existing network.

It has long been acknowledged that full network integration is a desirable objective, but technological barriers have in the past seemed too large to overcome. Chapter V of this thesis describes how recent advances in areas such as transmission and switching have led us to believe that fully integrated digital networks and services are in fact now an attainable goal. Before examining these new techniques however, it is useful to understand the framework within which these techniques were developed. Accordingly, the next chapter describes the development and acceptance of universal standards, which cannot be separated from a study of network integration.

IV. PROTOCOLS AND STANDARDS

Protocols and standards[3] may be considered the telecommunications "rules of the game," devised to establish and maintain communications between points on the network. System interoperability and adaptability are necessary to enable information exchange among diverse users, and the obvious method of achieving this is through common standards.

There are widely acknowledged practical motivations for developing and recognizing standards. By definition, communication involves two entities, also called end systems or peers. For communication to be accomplished, a fairly large number of functions must be carried out. To adequately carry out these functions, agreements must exist between the two end systems on how to undertake these functions, hence the need for standards. (Minoli,1991,p.533)

A. MIGRATION TOWARD UNIVERSAL STANDARDS

Industry and government are gradually migrating toward universally accepted communications and networking standards. Although there may be classified military

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[3]As noted in the previous chapter, publicly agreed upon protocols are known as standards. Protocols must be shown to have "multiple implementable" capabilities prior to being acepted as standards.

systems which will not lend themselves to universal standards, for the most part the U.S. military is moving along with industry toward implementation of commonly accepted standards. However, a great deal of proprietary and vendor-unique standards still exist. One must become familiar with at least the more widely used of these standards to be able to adequately assess all options for internetworking capabilities. The prevailing U.S. military philosophy is "don't reinvent the wheel" regarding implementation of standards. That is, communications planners should select widely-used non-proprietary commercial standards whenever possible to satisfy mission needs. Accordingly, this chapter provides an overview of several such standards.

In addition to the benefits that adherence to standards offers to joint and combined military operations, standards also allow cost savings. This is especially important with today's limited military budget. The cost of developing modern telecommunications equipment is very high. However, once designed, the unit production costs are typically quite low. For software the situation is even more extreme; development costs are very high but replication costs are almost insignificant. For this reason it is important that any product gets the widest possible use to spread development costs. Worldwide standards against which all telecommunications and users may purchase are therefore very

important. Standards also provide a framework for technological innovation and form the basis for verification of application-independent building block interoperability. This then facilitates interworking between different networks. (Griffiths,1992,pp.72-78)

B. STANDARDS MAKING BODIES

The U.S. military has a vested interest in the proceedings of national and international standards-making organizations, and therefore needs to remain actively involved with their ongoing activities. The purpose of military involvement is to inform these organizations of military needs, to influence, and to coerce if necessary to help ensure that military requirements are known and satisfied. The major standards-development organizations which were introduced in Chapter II are discussed further below. (Stallings,1991,pp.23-27)

1. International Organization for Standardization (ISO)

The ISO is a non-government body created to promote the development of standardization and related activities, to facilitate international exchange of goods and services and to develop cooperation in the sphere of intellectual, scientific, technological, and economic activity. Although not a government body, more than 70 percent of ISO member bodies are governmental standards institutions or organizations incorporated by public law.

2. American National Standards Institute (ANSI)

The ANSI is a non-profit, non-government federation of standards-making and standards-using organizations. Its members include professional societies, trade associations, governmental and regulatory bodies, industrial companies and consumer groups. The ANSI is the national clearing house for voluntary standards in the U.S. and is also the U.S.-designated voting member of the ISO.

3. International Telegraph and Telephone Consultative Committee (CCITT)

The CCITT is a committee of the International Telecommunications Union (ITU), which is a United Nations treaty organization. The members of the CCITT are therefore governments. The CCITT's primary objective is to standardize techniques and operations in telecommunication connections, regardless of the countries of origin and destination. The CCITT makes recommendations which are issued in several series.

4. Institute of Electrical and Electronics Engineers (IEEE)

The IEEE is a professional society and a member of the ANSI. The IEEE is primarily concerned with the lowest two (physical and data link) layers of the OSI reference model, which is discussed later in this chapter.

5. Electronics Industries Association (EIA)

The EIA is a trade association of electronics firms and a member of the ANSI. The EIA is primarily concerned with standards that fit into OSI layer one, the physical layer dealing with electrical, mechanical and procedural characteristics of data communications.

6. National Institute of Standards and Technology (NIST)

The NIST is a member of the U.S. Department of Commerce, responsible for satisfying federal government requirements with standards that are compatible with international standards. The NIST issues Federal Information Processing Standards (FIPS) for equipment sold to the federal government.

7. Defense Information Systems Agency (DISA)

The DISA is a DoD agency that provides architectural guidance for national, joint, and combined DoD C3 systems. The DISA promulgates communications-related military standards (MIL-STD), and works closely with the NIST.

C. THE LAYER OR MODULE VIEW

1. Background

It takes coordinated efforts in telecommunications to provide and utilize the available facilities and services. Most basically, transmission media such as optical fiber or copper pair must be provided, signalling and speech coding must be accomplished, and customers must

need to exchange information. Thus there is a natural layering of the telecommunications process. A layer is a defined set of related communication functions, and the layering or module view is a logical method of viewing a telecommunications system. The following are among the benefits that layering provides. (Minoli,1991,pp.536-544)

- Easier understanding of the communication process is possible by working with a small number of logical. groupings.
- Collecting related functions in the same groupings minimizes the number of interactions between layers and simplifies the interfaces.
- Layers can be implemented differently and changed to take advantage of new developments without affecting the other layers (modularity).
- Simple layer boundaries can be created with at most only two neighbors.
- Each layer offers certain services to the layers above, shielding those layers from the details of how the offered services are actually implemented.

2. Open Systems Interconnection (OSI) Reference Model (OSIRM)

The OSI is a term for the agreed international standards by which communications and computer systems should communicate. The OSI is designed to implement a common set of conventions for computer communications and computer networking. The International Standards Organization (ISO) has formalized these conventions into seven layers for the interworking of computers, terminals and applications. This seven-layer model and its functions should be committed to memory by anyone seriously interested

in telecommunications internetworking, as one can expect to encounter this model repeatedly. Any study of integrated services, signalling, or networks, for example, will require an understanding of the OSIRM and related recommendations. Much research and negotiations have gone into the model's development, and although there are many other vendor-specific models, they are typically variations of the OSIRM and are described in terms of their relationship to this universally accepted model.

In the OSIRM it is assumed that one has a physical connection such as an optical fiber, copper pair or coaxial line. Upon this the following is built: (Stallings,1991,pp.452-455)

- Layer one, the *physical layer*, which defines the characteristics of the signal to be transferred over the bearer. It covers such things as pulse amplitudes, line coding, transmission rates, connectors, and anything else needed to transfer digits satisfactorily.

- Layer two, the *data link layer*, which provides discipline for the assembling of the digits. It provides error detection and correction by assembling the digits into frames.

- Layer three, the *network layer*, which ensures that messages are routed to the appropriate destinations, and also provides mechanisms to ensure the appropriate control and acknowledgement of messages.

- Layer four, the *transport layer*, which is the terminal-to-terminal layer. Data may be carried across the networks using various forms of layers one, two, and three, but the terminals must have information at appropriate rates.

- Layer five, the *session layer*, which defines the way in which applications running at the two ends of the link intercommunicate, including initiation and termination of sessions and co-ordinating their activity during the session.

- Layer six, the *presentation layer*, which establishes the common format which is to be used between terminals, using common rules for representing data.

- Layer seven, the *application layer*, which is the actual task to be performed; for example, file transfer, airline booking, or message handling.

The seven-layer OSIRM is depicted in Figure 3, which is greatly simplified, but illustrates the type of diagram used to depict message flows. (Lini,1990,p.9)

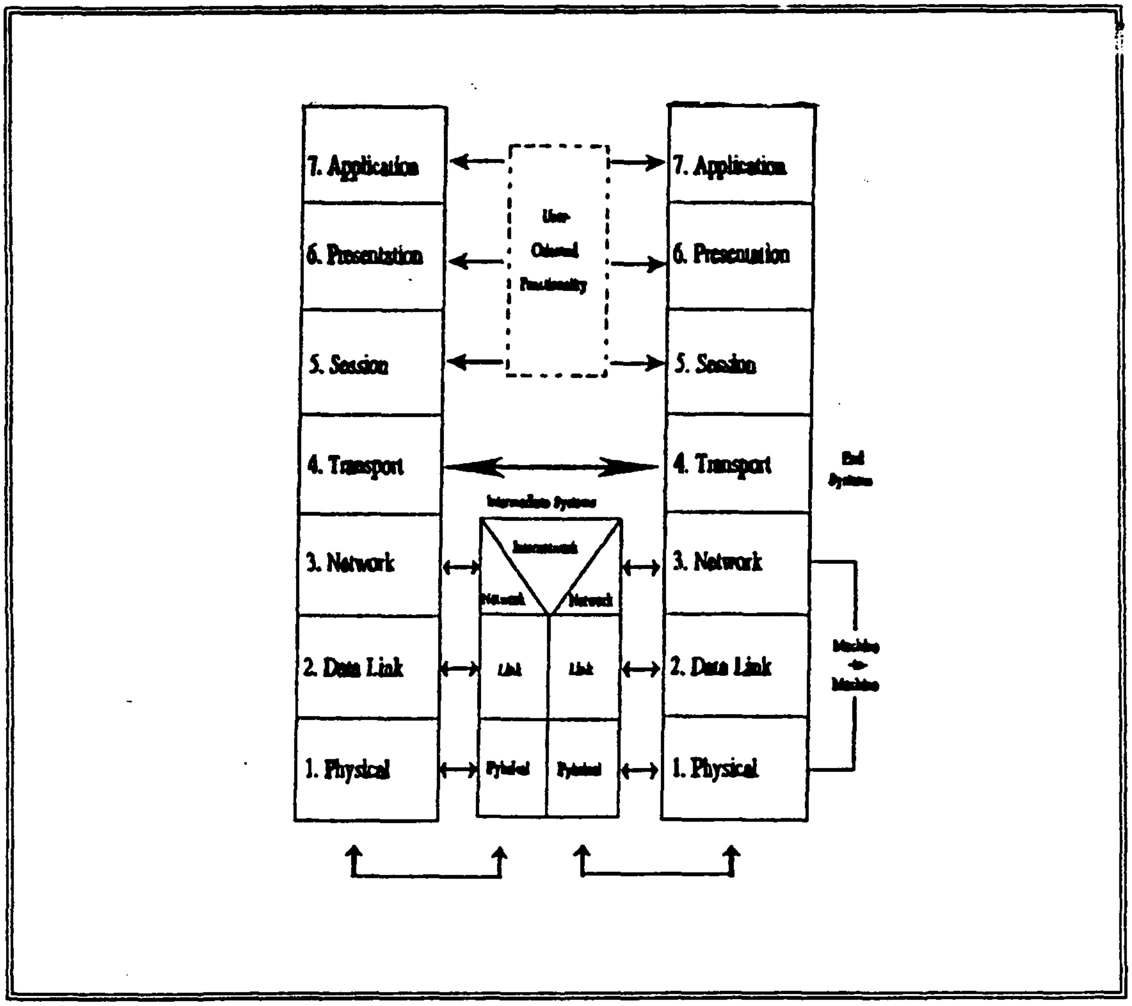

Figure 3
OSI Reference Model Layers

A complication often arises from the fact that the seven-layered model is in no way absolute and sub-layers can typically be identified. As a result, diagrams with dotted intermediate levels are often encountered.

D. DOD PROTOCOLS

In the early 1970s, the Defense Advanced Research Projects Agency (DARPA) funded work to develop network standards specifying the details of how computers communicate, as well as a set of conventions for interconnecting networks and routing information. The result was the Advanced Research Projects Agency Network (ARPANET). From these beginnings came today's Internet as well as the Defense Data Network (DDN). (Minoli,1991,p.95)

The DoD also took the lead in defining early protocols for network communications. In fact, the DoD entered this field prior to the widespread availability of OSI-based products. As a result, the military protocol suite known as the Transmission Control Protocol/Internet Protocol, often referred to as TCP/IP, soon became commonly used for the upper layers. The TCP/IP became accepted throughout the industry, and is now a well-entrenched defacto standard in meeting interoperability requirements. The DoD also developed a hierarchical or layered structure, much like the OSI reference model, to describe internetworking functions. The DoD layered model is shown in Figure 4. (Stallings,1988,p.6)

Process Layer FTP SMTP Telnet
Host-to-Host Layer TCP
Internet Layer IP
Network Access Layer

Figure 4
DoD Layered Model

The following provides a brief overview of the DoD protocols and their characteristics.

1. The Transmission Control Protocol (TCP)

The TCP provides a reliable mechanism for the exchange of data between processes in different computers (provides integrity). The TCP ensures that data are delivered error-free, in sequence, with no loss or duplication. Working at the equivalent of OSIRM layers four and five, the TCP relieves higher level software of the burden of managing the intervening communications facility. Because the transport protocol provides for high quality service and may need to deal with a range of communications services, this layer is one of the most complex of all communications protocols. (Stallings,1988,p.17)

2. The Internet Protocol (IP)

The IP provides the ability to interconnect various networks so that any two stations on any of the constituent networks can communicate. In general, IP is responsible for internetwork routing and delivery, and relies on a layer three at each network for intranetwork services. The IP is sometimes referred to as "layer 3.5" of the OSIRM. It provides unreliable connectionless service: no guarantee of delivery and packets may arrive out of sequence. (Stallings,1991,p.44)

3. The File Transfer Protocol (FTP)

The FTP provides for end-user transfer of files. The FTP supports both local and remote interactived or unattended file transfer. The user's communication with the FTP is mediated by the operating system, which contains input/output drivers. Users on one system can retrieve files, place files, or transfer files to a third party if access privileges are provided.

4. The Simple Mail Transfer Protocol (SMTP)

The SMTP provides for a network electronic mail facility. It provides a mechanism for transferring messages among separate systems. Users gain access to mail via a "mailbox" dedicated to them on a computer system.

5. The Telnet Protocol

The Telnet protocol specifies a virtual, network-standard terminal used to link users to both local and

remote applications. This protocol allows users to interoperate with a variety of geographically separated system.

The DoD protocols with the associated MIL-STD numbers are provided in Table 1. (Martin,1991,p.49)

TABLE 1
DOD MILITARY PROTOCOL DOCUMENTATION

Document	Title	Description
MIL-STD-1777	Internet Protocol	Connectionless service for end systems accross networks. Assumes an unreliable network.
MIL-STD-1778	Transmission Control Protocol	Reliable end-to-end service. Equivalent to ISO Transport Class 4.
MIL-STD-1780	File Transfer Protocol	A simple application for transfer of ASCII, EBCDIC, and binary files.
MIL-STD-1781	Simple Mail Transfer Protocol	A simple electronic mail facility.
MIL-STD-1782	Telnet Protocol	Provides a simple asychronous terminal capability.

E. The Government Open System Interconnection Profile (GOSIP)

The GOSIP is a subset of the OSI and defines the federal standards for data communications services. It is a government-mandated standard which must be used by all agencies in the procurement of new data communications equipment or enhancements to existing systems. The framework for future military network architectures are to be based on the GOSIP standard. The purpose of the GOSIP is to promote compatibility between government agency systems across a variety of networks. It represents a profile that is based on stable international standards developed by the ISO and the CCITT. Using the OSI as a foundation, the GOSIP provides a framework from which military and governmental agencies should strive to meet interoperability requirements. The GOSIP describes a selected number of OSI protocols from each layer of the OSIRM needed for true functionality.

The GOSIP architecture is depicted in Figure 5 (Lini,1990,p.9)

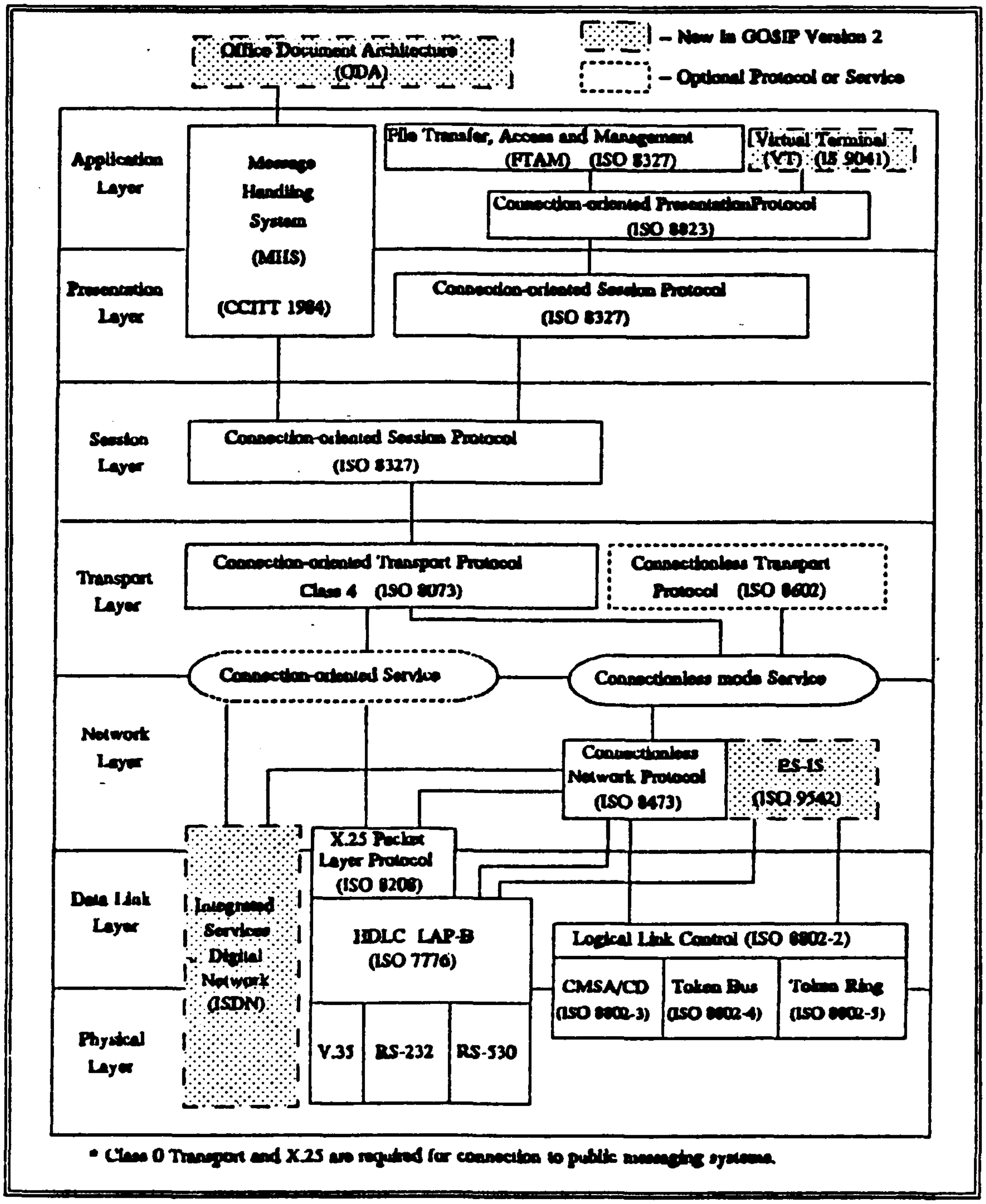

Figure 5
GOSIP Architecture

CHAPTER V. SWITCHING AND TRANSMISSION

This chapter takes a look at telecommunications switching and transmission equipment and techniques. In recent years, significant advances have been made in the area of switching and transmission devices. It is due largely to these incredible advances that the ultimate goal of fully integrated communications services is considered attainable.

Switching and transmission functions are closely interrelated, and there is a tradeoff between switching costs and transmission costs which depends largely on the implementation methods used to build switching and transmission facilities. The telephone industry is used as an illustration of switching and transmission costs comparison.

A. DEDICATED VERSUS SWITCHED SERVICES

To gain an appreciation for the benefits of switching techniques to telecommunications internetworking, one must first compare switched services to dedicated services. Dedicated services require a point-to-point link between two locations for the exchange of information. An obvious advantage of such a dedicated line is that the customer will always have the line for his own use, with no sharing among other users. Of course, this direct connection allows

little flexibility if data must be shared with more than one location. Furthermore, dedicated lines do not allow other users to take advantage of idle time on the line. With these dedicated line services, the number of lines required for a fully-interconnected network is calculated as N(N-1)/2, where N is the number of nodes (users on the network). As the number of users increases, one can readily see that the number of lines required can become enormous. In fact, such dedicated services may quickly become impractical and unwieldly, as well as prohibitively expensive. (Stallings,1991,p.214)

An alternative connectivity solution brings the user's line to a switching center, where connections are made between pairs of users. Thus only N wires are needed to interconnect N users. However, a switching mechanism to interconnect the N lines incident to the switching center is needed. In the telephone industry, this network is called the local access network. Figures 6 and 7 illustrate the lines needed for direct connections versus centralized switching. (Hui,1990,p.2)

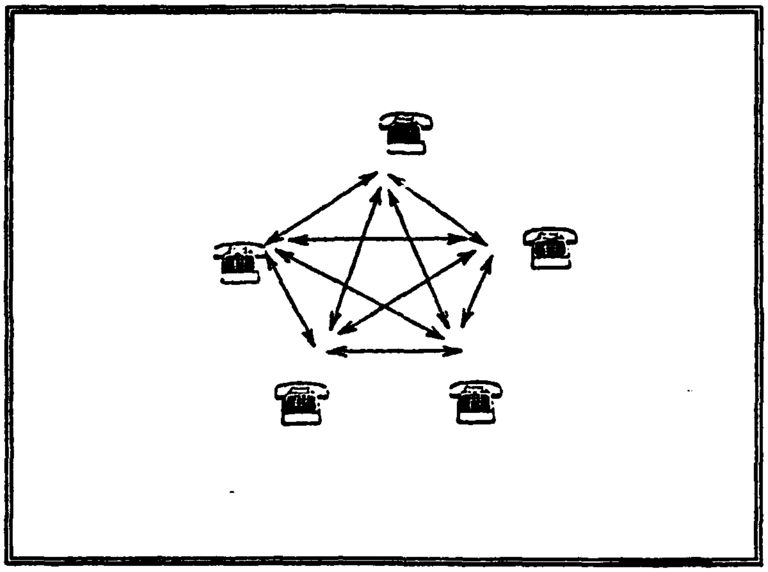

Figure 6.
Switching by Direct Connection

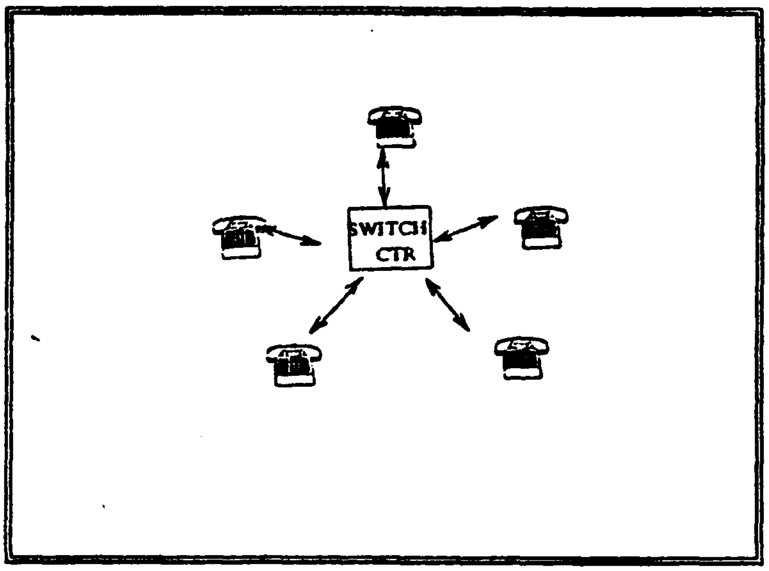

Figure 7.
Centralized Switching
by Local Access Network

Continuing with the telephone industry as an illustration, the hierarchical structure of the network becomes apparent. This practical example also illustrates how networking involves a tradeoff between transmission cost and switching cost at each level of the network hierarchy.

To facilitate telephone communications between areas served by different switching centers, wire connections called trunks are used between pairs of switching centers. The grouping of trunks between two switching centers is called a trunk group. To interconnect N switching centers, we may need at least N(N-1)/2 trunk groups. In practice, it may not be convenient to provide a trunk group between every pair of switching centers. Without a direct trunk group between two switching centers, a telephone connection may have to be made through other switching centers as intermediate nodes. We call this network between the local switching centers the exchange network. (Hui,1990,p.3)

For calls traversing even longer distances, each switching center is connected to a long distance switching center which routes the call to other long distance switching centers or local switching centers. A direct long distance trunk group may connect the local switching center to the long distance center, or the connection may be made via the exchange network. We call this network the long distance network. Hence a hierarchical network is created, as shown in Figure 8. (Hui,1990,p.4)

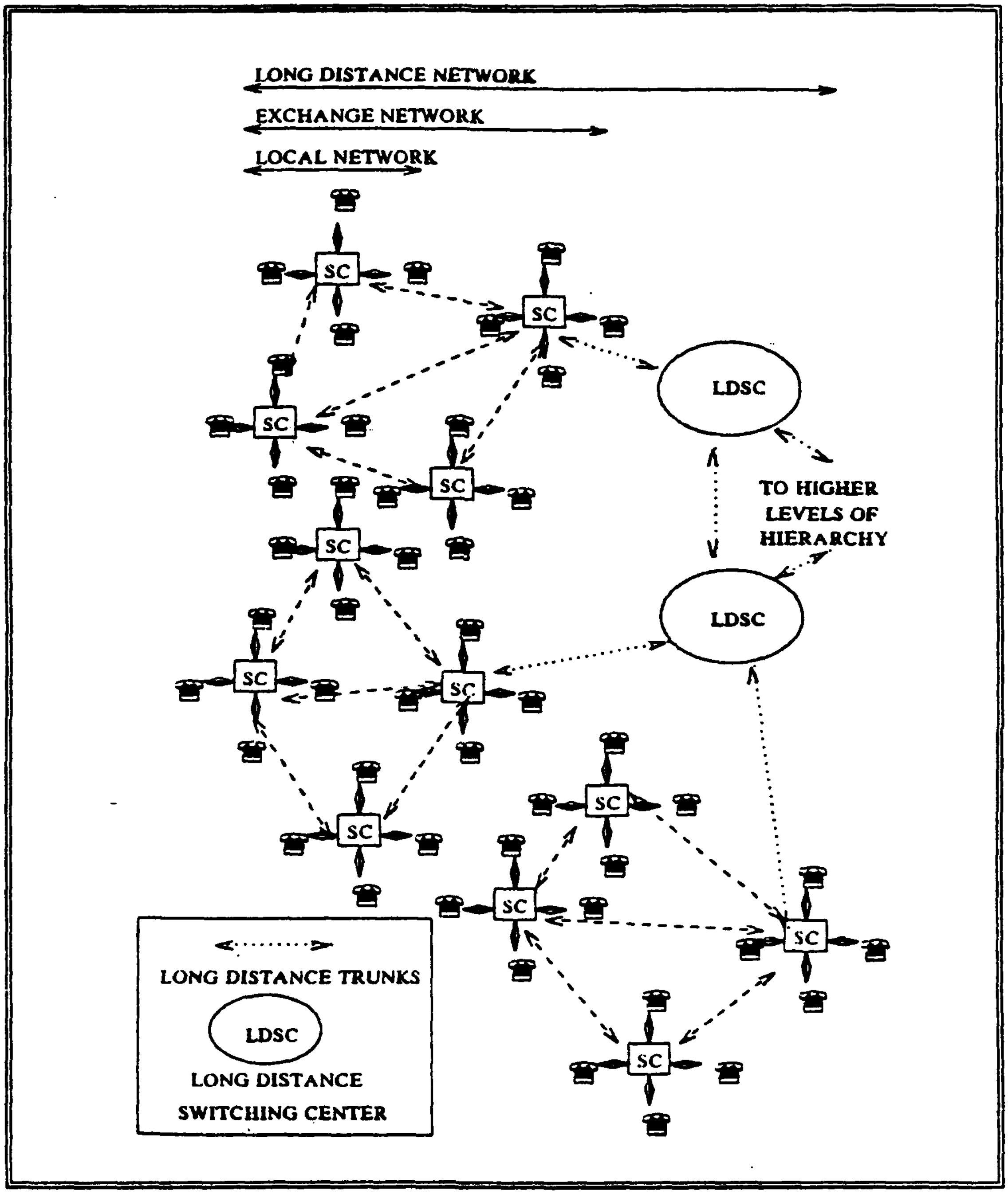

Figure 8.
The Hierarchical Network

This hierarchy is created for the purpose of concentrating traffic from the lower levels of the hierarchy to the higher levels. This concentration reduces the transmission cost for making a connection between two distant telephones at the expense of increased switching cost in the hierarchy of switching centers. Network design therefore involves a tradeoff between transmission cost and switching cost at each level of the network hierarchy. Without a local switching center, every telephone would require a direct link to every other telephone. Hence the total number of transmission links grows quadratically with the number of telephones. Given that telephones are switched by local switching centers, there is a tradeoff between the size of the area served by a switching center versus the total number of switching centers. Having small centers would require more centers to serve a fixed size area, but the switches and local access wires would be less costly. Again the total number of pairs of switching centers grows quadratically as the number of switching centers, resulting in increased trunking costs. This trunking cost can be reduced by employing a long distance switching center one level up the network hierarchy, with reduced number of direct links between widely separated local switching centers but requiring large capacity switches for routing long distance traffic. (Hui,1990,p.5)

As explained above, switched services are designed to

provide better line efficiency and flexibility at a lower overall cost than that of dedicated services. Users have the ability to reach any other user on the network, needing far fewer total links between users. Switched networks also provide redundant or alternate paths.

B. SWITCHING METHODS

Having considered the practical benefits of switched services, we can now consider some of the methods used to accomplish switching. There are at least six recognized types of switching for data and voice communication. This section looks at four of the most common switching methods used in switched networks. These methods are circuit, message, packet and fast packet switching. (Stallings,1991,pp.217-224)

1. Circuit Switching

In a circuit switched connection, the end-to-end path of a fixed bandwidth exists only for the duration of the communication session. Setting up a path between two locations using this method consists of three phases:

- Circuit establishment
- Information transfer
- Circuit disconnect

While a connection is established (by the network) for the time needed, the end destination can be virtually anyone with the proper end-equipment. Circuit switching is not only suitable for voice transmission, which employs this

method almost exclusively, but also for data transmission. Two well-known examples of circuit switched networks are the civilian Public Switched Telephone Network (PSTN) and the DoD Defense Switched Network (DSN).

Circuit switching is a connection-oriented (CONS) type of switching. With CONS switching, communication is initiated through a call request phase, which establishes an end-to-end path. After the information transfer phase that lasts as long as needed, the communication path is taken down via a call clearing phase.

Switched networks use a "backbone" of interconnected sites to establish the circuits between customers (or users). In essence, this allows many users to share the resources on an as-needed basis, instead of trying to run their own dedicated lines. Once a call is completed, the backbone frees the circuit(s) to be used by other customers. This maximizes the use of the line as compared to idle time on a dedicated line.

One of the drawbacks to a circuit switched network is that not all customers can be served at the same time. Anyone who has tried to place a call during peak times on the PSTN and has been "blocked" knows that the increase in efficiency comes at the expense of a reduced ability to accept surges in demand. In addition, both users generally need to be available at the same time for the information exchange to take place. While this feature is desirable

(and usually necessary) for voice communication, it does not allow information to be sent when both parties are not available. The switching techniques presented in the following sections enable users to send electronic messages even when the intended recipient is not available at the time of transmission.

Both message and packet switching methods described in the following sections are regarded as connectionless (CNLS) switching. With CNLS switching, the end-to-end route is not decided a priori, but each packet can take an independent route that may be a function of real-time parameters such as traffic congestion, link outages, node overload, delay, or cost.

2. Message Switching

Message switching refers to a method of storing a message at intermediary nodes in the network for more than a couple of minutes. This method was commonly used in telegraphy and telex networks. It almost disappeared, but may now be reemerging in store-and-forward electronic mail systems.

Message switching does not require that a dedicated path be established prior to and for the duration of information exchange. Information is packaged into a message block and inserted into the message switching network along with the address of the intended recipient. The switch receives the message, temporarily stores it while

making a routing decision, and then forwards it along the path it has determined to be the best. Later switches will do the same until it is received by the switch connected to the intended recipient, which will forward it to the customer. This process is called the "datagram" approach to routing, where the entire message is received and buffered at the switch before a routing decision will be made. It will base the decision upon the traffic loads of various paths, and the end destination.

An advantage to this method is that the sender and receiver do not need to be available at the same time. Messages can be stored at the end destination until the recipient "picks them up," much like checking the mail of a mailbox. Because paths are allocated dynamically, delays through the network will vary from message to message, even between the same end-points. As such, message switching is not well suited to real-time or interactive traffic. The "MailGram" service offered by the U.S. Postal Service is an example of using message switching:

- The message is taken to a post office and transmitted electronically to another post office.
- At the receiving post office, the message is printed and placed in an envelope.
- The message is hand delivered to the destination.

The process is faster than the regular mail, but slower than the phone. The distinction is that, other than at the two end-points, what moves is not the letter but the

message that it contains. Because the message length is not restricted, message switching works well for shorter length messages, but tends to bog down on longer messages. This is due to the process of storing the message in a buffer at each node and making a routing decision prior to sending it out. Packet switching, the switching technique discussed in the following section, attempts to alleviate some of the problems of message switching while retaining the advantages.

3. Packet Switching

It soon became apparent that the dynamic allocation of bandwidth would allow more efficient utilization of available network resources for interactive data communication. Packet switching thus emerged as an important approach in data networks. In packet switching, messages are exchanged as blocks of limited size or "packets." At the source, long messages are divided into several packets that are transmitted across the network and then reassembled at the destination to reconstitute the original message. Packet switching can be viewed as an extension of message switching, but with a limit placed on the transmitted block size. Each message is broken into packets of a standard size, each of which contains information on its place in the original message and the intended recipient. These packets are then placed into the packet switched network (PSN) for routing much the same as

for the message switching network. However, where the message switched network can only use the "datagram" approach to routing, the PSN can use either datagram or "virtual circuits." As noted earlier, the datagram approach makes a routing decision for each message. For the PSN, the datagram approach makes a routing decision for each individual packet, so each packet of a message could take a very different path prior to reaching the destination node. (Stallings,1992,pp.71-92)

The virtual circuit approach makes a single routing decision for all the packets in a message prior to transmission, and places a virtual circuit identifier in each packet. However, the path is not dedicated as in circuit switching; packets are still buffered at the switches and queued for output. The difference is that the routing decision is made only once for the entire message or groups of messages sent at the same time between two end-points. For lengthy transmissions, the virtual circuit approach can save processing time over the datagram approach. Packets will also arrive in order since they travel the same path. The datagram approach saves the call set-up phase (to establish the virtual circuit) and is generally more adaptive to changes in network congestion or nodal failures than virtual circuits.

The best known and most widely used packet switching service is CCITT X.25. This traditional packet switching

service specifies an interface between a host system and a wide area packet-switched network. What happens when a packet enters the network is not defined. The network simply delivers the packet to the edge of the network closest to its destination, where the X.25 protocols are used to interact with the destination node. Because X.25 is an interface with the internals undefined, X.25 PSN is usually represented as a cloud.

Whereas packet switching was developed to operate in an environment characterized primarily by relatively low-speed transmission facilities and high bit-error rates (BER), high speed transmission facilities with low BER are becoming increasingly important today. This evolution has led to the concept of fast packet switching, which refers to the exploitation of packet switching in a high speed environment.

4. Fast Packet Switching

The most recent innovation in switching methods, that of fast packet switching, represents a significant technological leap beyond the three techniques discussed above. It is largely due to the capabilities offered by fast packet switching that much of the internetworking and integration advances discussed in Chapter VII of this thesis are made possible.

Fast packet switching is a "streamlined" packet switching technique that provides the benefits of reduced

protocol processing (i.e., high throughput and low delay) while retaining the advantage of packet switching (i.e., efficient use of transmission facilities). Streamlining is designed to overcome some of the weaknesses of traditional packet switching such as large and variable delays. (Stallings,1992,pp.111-118)

Fast packet switching methods include two evolving technologies--frame relay and cell relay.

Cell relay switching methods such as asynchronous transfer mode (ATM) are next generation cell-switching techniques that package data in 53-byte fixed-length cells for high-speed transmission. Each cell is composed of a five-byte header and 48 bytes of data. Because this is fixed-cell it provides uniform delay, which is ideally suited to support voice and video transmission. It is designed to let users transmit any type of information in standard ATM cells, which can be transmitted over multiple physical transport systems.

Frame relay switching methods enclose variable-sized user packets in larger packets (called frames). Frames may vary greatly in length up to some design limit, usually 1,000 bytes or more. Frame relay is a service that is used across the interface between user devices[4] such as routers,

[4]A user device is often referred to as a data terminal equipment (DTE), while network equipment that interfaces to a DTE is referred to as data circuit terminating equipment (DCE).

bridges, and switching nodes. As an interface to a network, frame relay provides the same type of service as X.25. However, frame relay differs significantly from X.25 in its functionality and format. Figure 9 depicts interconnections using frame relay. (Cisco,1992,p.1)

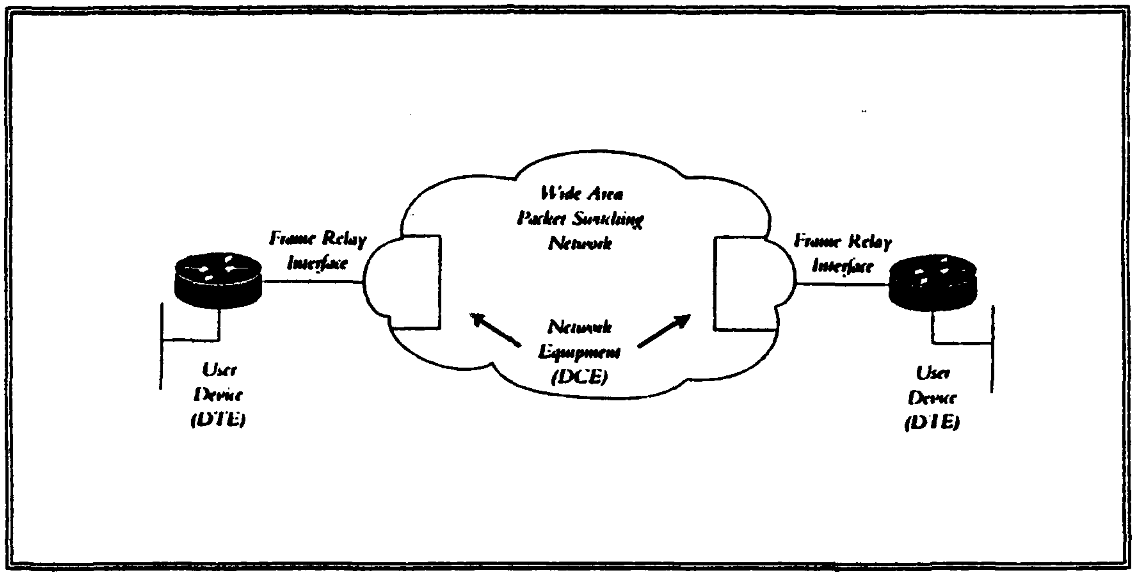

Figure 9.
Router Interconnection Using Frame Relay

In order to appreciate the significance of the advances which frame relay offers, it is useful to compare it with services offered by X.25. The X.25 interface protocol pre-dates the development and universal recognition of the OSI reference model (OSIRM). In fact, X.25 dates back to the time when master-slave protocol relationships predominated, as opposed to the "here to here" protocol demonstrated with the OSIRM. As a result, X.25 carries several extra features or "overhead" which often are no

longer necessary or even desirable, as they tend to complicate and slow down the communication process. In many cases features of X.25 "protrude into" upper layers, being duplicated in the TCP, IP and higher protocols. For example, TCP uses end-to-end error checking. Using X.25 with TCP therefore results in duplicate error checking, as X.25 does error checking for each individual segment or link. With frame relay, unlike X.25, no error checking is done on links. This is based upon the recognition that transmission media (especially optical fiber) is now so reliable that it is practical to omit error checking for links, since the probability of error is so low. Frame relay takes advantage of the superior error performance of fiber optics by eliminating elaborate step-by-step error detection and retransmission. This allows the intermediate or transit nodes to forward packets with less processing and less transit delay as compared with X.25 networks. Frame relay may be considered a "stripped down" version of X.25 optimized for current high-quality transmission capabilities. (Griffiths,1990,p.112)

Frame relay may be used as an interface to either a publicly available carrier-provided service, or to a network of privately owned equipment. A typical means of private network implementation is to equip traditional T1 multiplexor equipment with frame relay interfaces for data

devices, as well as non-frame relay interfaces for other applications such as voice and video-teleconferencing. This configuration is shown in Figure 10. (Cisco,1992,p.8)

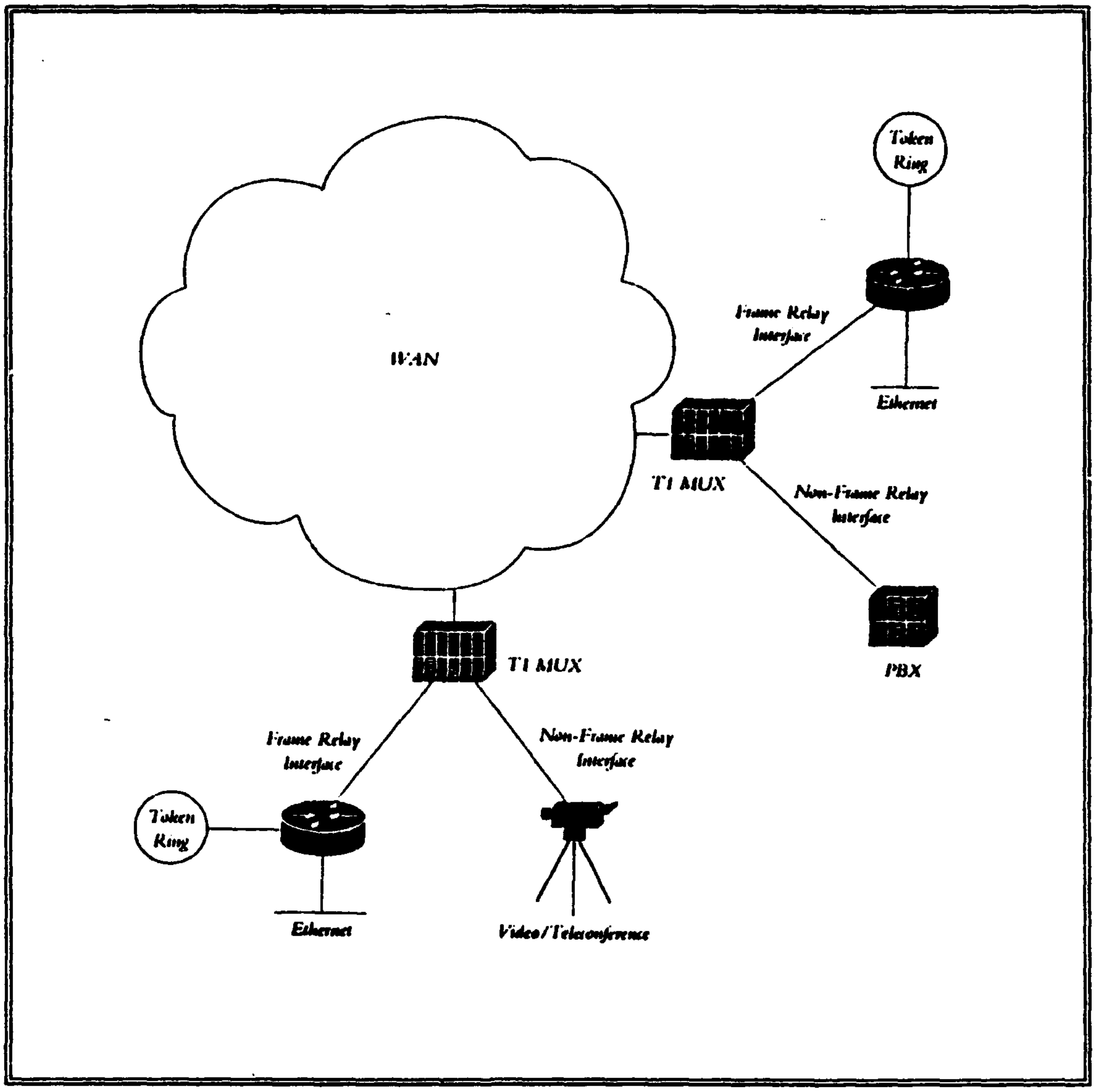

Figure 10.
A Hybrid Frame Relay Network

C. TRANSMISSION

Almost in parallel with the development of large electronic switching systems, long distance transmission techniques matured. Digital transmission systems have become increasingly important, and they are critical to the network design and integration issues discussed in this thesis. Nevertheless, many of the characteristics of digital transmission systems were inherited from voice (analog) systems, so a look at these analog systems can help pave the way for a closer look at digital systems.

A transmission system is often considered to be made up of multiplexing equipment and a transmission link. To understand transmission systems, we therefore need to become familiar with multiplexing fundamentals and techniques.

1. Multiplexing

Multiplexing refers to placing multiple channels on one medium, and there are a number of multiplexing schemes to accomplish this. One of the objectives of multiplexing is to minimize the number of discrete physical channels needed. The two most commonly multiplexing methods are Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM). FDM is typical of an analog carrier system and is gradually disappearing except in analog microwave transmission. TDM is typical of digital transmission, and it lends itself well to computer interfaces. Time division techniques are becoming prevalent

because of the increased deployment of digital networks and the lower cost to achieve multiplexing compared to analog techniques. (Minoli,1991,p.104)

A more detailed review of multiplexing equipment development in the telephone industry may help to understand its current implementations. As noted above, analog voice signals were multiplexed via FDM on high capacity transmission media, with each signal using a frequency slot in the frequency spectrum. Once multiplexed, these signals could be amplified and transmitted at low cost over long distances. However, the relatively high cost of multiplexing made these wide band transmission systems suitable only for long distance and high volume routes for which the reduction in transmission cost more than compensated for the increase in multiplexing cost. Thus, the deployment of FDM consolidated the long distance network into fewer routes with higher capacity.

With lowered cost and increased speed of digital electronics, the multiplexing cost of TDM became less costly than that for FDM. Thus, TDM was gradually used for the local access network and the exchange network, while analog FDM still dominated the long distance network due to its lower transmission cost. In the local access network, the application of time multiplexed digital transmission also enabled several telephones and data terminals to access the local switching center via a single wire.

Figure 11 depicts the trend toward integration of transmission and switching. (Stallings,1992,p.123)

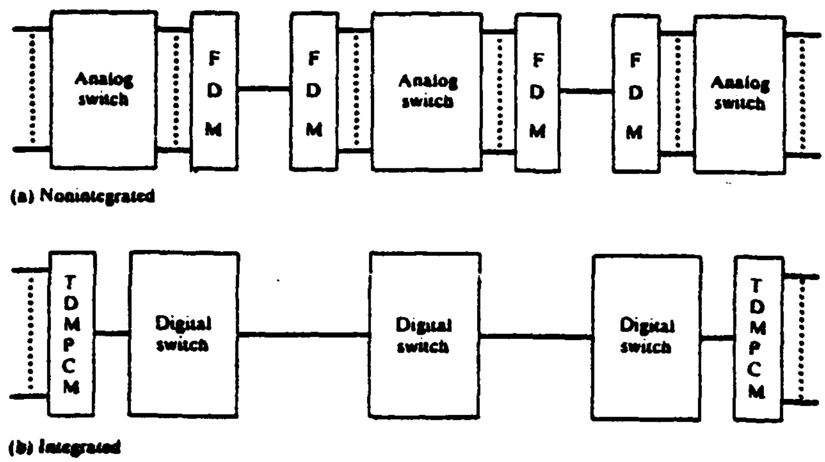

Figure 11.
The Integration of Transmission and Switching

It is worth noting here that TDM is considered more than just a multiplexing and transmission mechanism; it can also be used as a switching mechanism. Terminals or interfaces distributed along a shared transmission line may time multiplex their information transmission, and select the information from the transmission line destined for that terminal or interface. Therefore, "switched" connections are achieved for terminals served by the same transmission line. Consequently, the distinction between transmission and switching becomes less obvious in these network configurations.

2. Digital Carrier Systems

In the early days of electrical communications, a medium such as copper wire carried a single information channel. For economic reasons, in terms of both construction costs and material, it has been necessary to find ways of packing multiple channels onto a physical link. The resulting system is referred to as a carrier. Digital signals are now transmitted from one location to another by transmission facilities or systems using a multitude of media (unshielded or shielded twisted pair, coaxial cable, analog or digital radio, optical fibers, and satellite). (Datapro,1988,p.C05-010-601)

T-carriers, in the term's strictest sense, are copper-based digital facilities that carry 24, 96, 672, or 4,032 (the T1, T2, T3, and T4 systems, respectively) simultaneous digitized voice streams at 64 kbps each. In reality, the correct nomenclature for the digital carrier systems of today is Digital System 1 (DS1), DS2, DS3, and DS4. The term T-carrier has entered the popular lexicon and is therefore employed to refer to any digital carrier system.

An overview of carrier system bandwidths is provided in Table 2. (Datapro,1988,p.C05-010-608)

TABLE 2.
TDM DIGITAL HIERARCHY

Digital Levels	Level's Bandwidth (Mbps)	Transmission Facilities Copper	Radio	Optical
DS4	274.176	T4M	DR18	
DS3	44.736		3ARDS	FT3
DS2	6.312	T2		
DS1C	3.152	T1C,T1D		
DS1	1.544	T1,T1/OS	1ARDS	
DS0	0.064			
Analog	4 kHz			

The table shown above indicates the traditional TDM hierarchy, described in terms of DS levels 0 through 4. The 0-to-4 kHz nominal voiceband channels are first converted to digital by PCM-type techniques and then multiplexed onto higher bit streams. Each of the individual digitized 64 kbps channels are referred to as DS0 levels. Twenty-four voiceband analog channels are combined or multiplexed to form a DS1 signal (1.544 Mbps).

Table 3 provides another view of the U.S. standardized digital hierarchy, indicating the number of voice channels and combinations for the various T-carrier designations. (Stallings,1992,p.127)

TABLE 3.
CAPACITY OF SOME COMMUNICATIONS CARRIERS

Carrier Designation	Number of Voice Channels	Data Rate (Mbps)	Combinations		
T1	24	1.544	-	-	-
T1C	48	3.152	2-T1	-	-
T2	96	6.312	4-T1	2-T1C	-
T3	672	44.736	28-T1	14-T1C	7-T2
T4	4032	274.176	168-T1	84-T1C	42-T2

Several types of terminal equipment other than the basic switch are used to provide digital connectivity. The equipment can be grouped into three general component categories: terminals, multiplexers, and cross-connects. (Datapro,1988,p.C05-010-602)

Terminals take a continuous-wave analog input and transform it, through the use of sampling and encoding, into a digital stream. Channel banks are examples of terminals.

Digital multiplexers provide interfaces between the different bit rates in the digital network. This means stacking blocks of datastreams on top of each other before they enter a high-capacity medium.

Digital cross-connects are the interconnection points for terminals, multiplexers, and transmission facilities. They are equipment frames where cabling between the system components is cross connected to provide flexibility for restoration, automated rearrangements, and circuit order work.

The channel bank was one of the first types of termination-multiplexing equipment deployed. A channel bank performs the first step of call handling. It multiplexes a group of channels into a higher frequency band and, conversely, demultiplexes the higher frequency band into individual channels. Channel banks and carrier systems can be of the analog or digital type.

Analog channel banks are gradually being phased out with the move toward integrated digital systems. Digital channel banks are becoming increasingly prevalent, and have two functions: They convert analog voice to digital code and vice versa, and they combine or multiplex the resulting digital streams from several active sessions (voice or data) onto a single stream. Channel banks may be viewed as specialized T1 multiplexers. There are a variety of channel bank frame formats corresponding to generations of equipment. Examples of these frame formats are D1, D2, D3/D4, and extended superframe format (ESF). (Datapro,1988,p.C05-010-603)

The T1 frame format evolved principally to carry voice streams, and data to be transmitted over a T-carrier system must conform to this format. The frame consists of 193 bits, with the last one always a framing bit. The first 192 bits correspond to 24 channels sampled with pulse code modulation (PCM) methods and generating eight-bit words. In the T1 (D1) framing structure, the 24-channel PCM system uses a seven-level code (e.g., $2^7 = 128$ quantizing steps). To every 7 bits representing a coded quantum step, 1 bit is added for signaling. To the full sequence one bit is added, called a framing bit. Therefore a T1 frame consists of $(7 + 1) \times 24 \times 1 = 193$ bits, making up a full sequence of frame. By definition 8000 frames are transmitted, so the bit rate is $193 \times 8000 = 1{,}544{,}000$ bps. (Freeman,1991,p.164)

A superframe is a repeating sequence of 12 frames as discussed above, and thus contains 12 framing/signaling bits. The D3 and D4 channel banks minimize the bandwidth spent on voice frequency signaling by putting signaling information only in every sixth frame. The D4 framing pattern is shown in Figure 12 (Datapro,1988,p.C05-010-610)

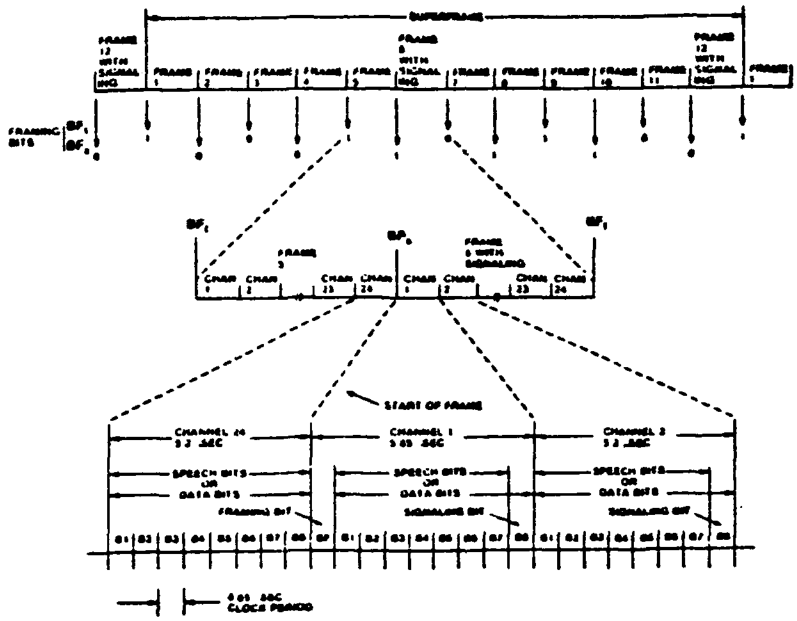

Figure 12.
D4 Framing Pattern

The extended superframe format (ESF) is a relatively new channel bank framing format which provides more reliable and advanced services. Among these services is the ability of users to reconfigure their networks in real time from a data terminal. The ESF has 24 frames in its definition of a superframe, but only six bits in its framing pattern. This means that instead of having to resynchronize every 1.5 milliseconds as in the regular format, it only needs to resynchronize every three milliseconds. The 193rd bits are viewed as an ensemble of 24-bit words. (Minoli,1991,p.114) Substantial progress has occurred in the VLSI manufacture of channel banks, so that they now keep timing much more accurately. This implies that fewer bits are required for this housekeeping function. The ESF takes advantage of this, and the result is that four kbps of channel are freed up without any loss of functionality or any additional bits. The ESF is illustrated in Figure 13. (Minoli,1991,p.115)

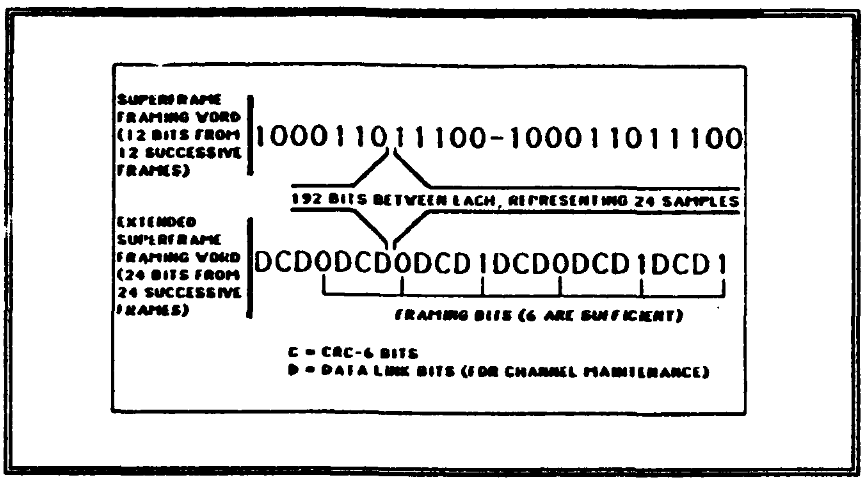

Figure 13.
The Extended Superframe Format

Technological developments in the past several years have allowed reliable transmission systems at tens or even hundreds of Gbps rates. In particular, optical transmission advances such as that of the synchronous optical network (SONET) have made possible the introduction of many broadband services that were not possible with copper-based networks.

The SONET is a set of emerging international network interface standards for optical (fiber optic cable) communications aimed at enabling global network interconnection. Fiber optics is the only medium available today to meet high-resolution video requirements and the multi-channel rate of the network to handle multiple users. The SONET defines a new multiplexing hierarchy that attempts to ensure equipment compatibility between offerings from different vendors. This new digital hierarchy is ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals. (Minoli,1991,pp.153-157)

The SONET is a high speed transmission method which operates at a basic signalling rate of 51.84 Mbps, called synchronous transport signal one (STS-1). Data rates of up to 2.488 Gbps are achievable using SONET techniques, as indicated in Table 4. (Minoli,1991,p.155)

TABLE 4.
SONET RATES

Signal Designation	Optical Signal Designation	Line Rates (Mbps)
STS-1	OC-1	51.84
STS-3	OC-3	155.52
STS-9	OC-9	466.56
STS-12	OC-12	622.08
STS-18	OC-18	933.12
STS-24	OC-24	1244.16
STS-36	OC-36	1866.24
STS-48	OC-48	2488.32

In essence, SONET is a high bandwidth optical standard that features its own optical carrier hierarchy, expressed in multiples of the basic rate of 51.84 Mbps. The primary goal of the SONET standards are to define a synchronous optical hierarchy with sufficient flexibility to carry many different capacity signals.

3. Modulator-demodulator (modem)

In spite of repeated predictions over the past decade that modems would soon be eliminated by end-to-end digital networks, the modem industry continues to prosper. While digital backbones are becoming popular, a large portion of data communication is still carried by voiceband modems over the analog telephone network. (Minoli,1991,p.43) The implementation of all-digital networks is taking place at different speeds in different regions of the world. In some areas, particularly rural and underdeveloped areas, the primary means of transmitting information will remain analog telephone lines for the foreseeable future. It is therefore appropriate to include a discussion of modems in this switching and transmission chapter.

Traditional telephone networks such as the PSTN and the DoD Automated Voice Network (AUTOVON) or DSN were originally developed to service voice traffic. Data can also be carried by the same networks when a modem is employed by users at each end of the link. In effect, the modem transforms the data into an acoustical signal that fits into the nominal 4-kHz bandwidth of a standard telephone channel. This method of carrying data is called voiceband or circuit-mode data. (Minoli,1991,p.9)

Analog voice signals vary in time in terms of amplitude and frequency. When sending data over an analog line, the modem takes the digital signal and produces a

signal suitable for transmission over the analog network. The analog signal generated by a modem to transmit data consists of a carrier frequency, plus sidebands that change as the data bit pattern varies. These side-bands must fit within the attenuation limits of the voice-grade channel.

Recent advances in modem capabilities have resulted in modems that are faster, smaller, cheaper, more reliable, and richer in features than ever before. Using very large-scale integration (VLSI) manufacturing techniques, vendors can now produce sophisticated high-speed modems in great abundance. Features once considered options such as auto dial, auto answer, and self diagnostics, are now standard on most modems. Also, many modems now operate with a network management system that allows central-site monitoring and control of a large number of units.

VI. NETWORKS AND INTERCONNECTIONS

As defined in Chapter III, internetworking refers to the capability of different networks to interact with each other. This chapter describes local, metropolitan and wide area networks, the three widely recognized categories of data networks, and discusses techniques and devices used to interconnect these networks.

A. BACKGROUND

In recent years, data networks have permeated industry, education, and the government at a pace similar to that of computer systems. In the early 1980s, networks were being installed mostly to provide information sharing within a localized community. These local area networks (LANs) were proprietary in nature and confined users to a closed environment. Users soon saw a need to share information outside their local community. Metropolitan area networks (MANs) extended the LAN capability within metropolitan range areas. Wide area networks (WANs) were developed to permit users from different parts of the country to communicate with each other transparently.

Under the auspices of the Defense Advanced Research Projects Agency (DARPA), the DoD took the lead in developing protocols, such as the transmission control protocol/internet protocol (TCP/IP), to achieve

interoperability. The increase in user application requirements later helped influence the development of high speed packet switching techniques and thus the development of global standards to promote interoperability between users. (Stallings,1988,p.6)

There are many benefits of internetworking, including the following:

- Sharing information (e.g., data files).
- Sharing software.
- Sharing hardware (e.g., printers).
- Diskless workstations.
- Sending messages (e.g., e-mail).

Among the possible disadvantages are higher cost and additional complexity, as well as network dependence on outside sources.

With the expanded possibilities offered by network interconnection, data networks are becoming increasingly important as part of a global infrastructure from which the joint military commanders can "pull" information as they need it. As the joint interoperable military environment is relying ever more heavily on these networks, they warrant a detailed level of discussion as provided in this chapter. It is largely through the technological innovations in data networks, along with the techniques and devices that interconnect them, that the U.S. is able to maintain its edge in overall warfighting superiority.

B. TYPES OF NETWORKS

The following sections look at the three general categories of data networks--LANs, MANs and WANs.

1. Local Area Networks (LANs)

LANs are designed to operate as high-speed low-cost data systems over a limited distance, usually linking terminals, personal computers and servers in a building or a group of buildings within a few miles of each other. Generally speaking, individual LANs are made up of various configurations of the following equipment and software: (Schatt,1992,pp.25-35)

- Workstations.
- File servers.
- Database servers.
- Print servers.
- Modem servers and fax servers.
- Cabling.
- Network interface cards.
- Network operating system.
- File server, name server, security server software.
- Application programs, generally stored on server.

A fundamental unit of data with which all LAN protocols work is the packet. A packet is generally of a certain specific size and consists of two basic parts:

- The data that is being sent.
- A header which identifies the node to which this data is addressed or intended.

The method used to allow connectivity of computers in a LAN is called the LAN's topology. One must consider both logical and physical topologies, as there often is a difference between the logical operation and the physical wiring of the network. (Schatt,1992,pp.40-45) Physically, the media used may be coaxial cable, unshielded twisted pair, shielded twisted pair, or fiber optic cable. The choice of media depends largely on the required transmission speed. Logically, LANs can exhibit either a bus, ring or star topology. With a bus topology, users or workstations have access to a common data path--a common data highway to which computers can be connected. A ring topology implies that all workstations are logically connected to a ring structure. With a star logical topology, users are connected to a central relay, much like spokes from a hub. Figure 14 depicts bus, ring and star topologies. (Stallings,1991,p.378)

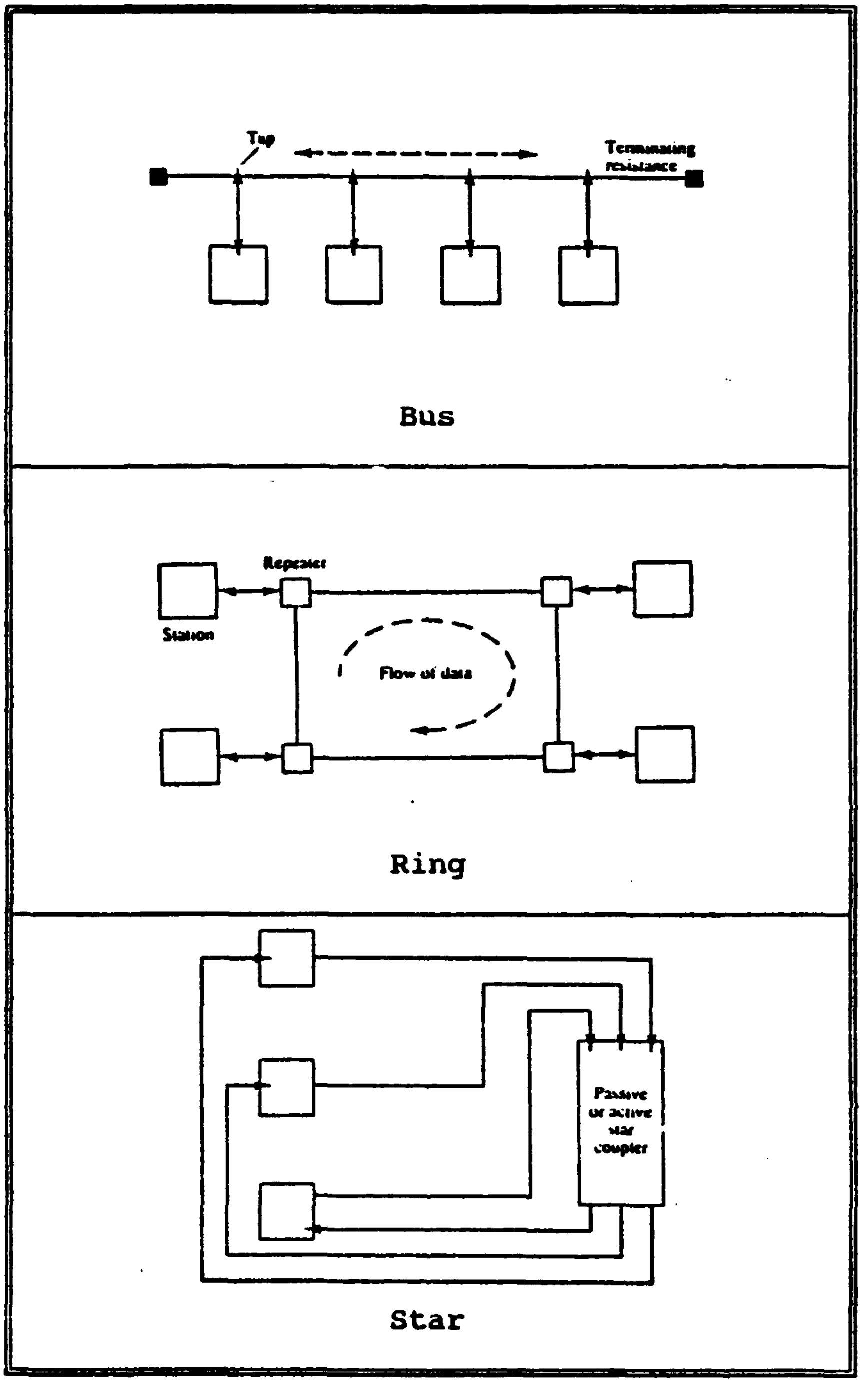

Figure 14.
Bus, Ring and Star Topologies

Table 5 provides examples from industry of five major types of LAN topologies currently in use. (Schatt,1992,pp.40-45)

TABLE 5.
MAJOR TYPES OF LAN TOPOLOGIES

Type	Logical	Physical
3COM Ethernet Baseband	Bus	Bus
IBM Ethernet Broadband (signal is modulated)	Bus	Star
ARCNET Token-Bus[5]	Ring	Bus
IBM Token-Ring	Ring	Star
AT&T Starlan	Star	Star

Ethernet and Token Ring currently have the largest market share, and are the topologies one most often sees referenced.

[5]In terms of logical operation token bus works like token ring but has a bus topology. This is possible because computers really do not have to be sequentially arranged physically to send messages - they can just be logically sequential.

A major consideration in the logical topology of a LAN is the access method, which is the way that a user gains access to the network. Two ways exist for ensuring that no user waits too long to gain access to the network, and that no more than one user at a time gains control of the LAN channel. The first is by the contention method; the second is by a variant of polling. The features of contention access types are as follows: (Minoli,1991,pp.608-611)

- Carrier Sense Multiple Access with Collision Detection (CSMA/CD): With this demand-access type of communications, all users compete for a bus or "data highway" at the same time. An example of this contention access method is Ethernet.

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA): With this contention access method, the network cable or bus is monitored with respect to traffic, and actions taken to prevent collisions. An example of this method is Apple Computer's Appletalk.

Managed access methods (polling) access methods use a "token" to determine access to the network. A potential user must have access to the token before passing information. A typical token-passing scheme is depicted in Figure 15. (Minoli,1991,p.676)

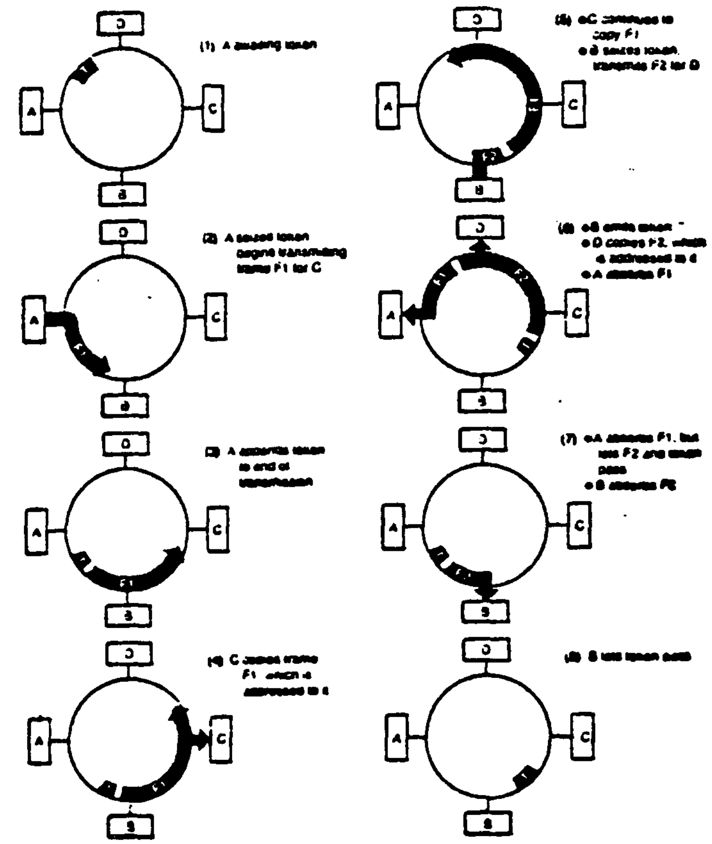

Figure 15.
Token-Passing Scheme

2. Metropolitan Area Networks (MANs)

A MAN is a high-speed network providing LAN-to-LAN and LAN-to-WAN connections for public or private communication systems within metropolitan-range distances.

A major consideration for LAN managers is ensuring that disparate LANs as discussed above can perform satisfactorily when interconnected. One innovative technique used to attain this goal is the Fiber Distributed Data Interface (FDDI) standard, which is finding widespread MAN application. The FDDI provides a token-passing 100 Mbps fiber backbone for interconnecting multiple LANs that is independent of the protocols used by the constituent LANs connected to the FDDI ring. In addition to this backbone application, FDDI can be used as a front-end technology, i.e., as a high-speed LAN for high-end workstations. The FDDI offers an industry-standard solution for organizations that need flexible, robust, high-performance, multivendor networks. The FDDI is based on multimode fiber optic media connected to form dual, counter-rotating rings. The FDDI is intended to meet needs ranging from high-speed backbone to small MANs. Up to 500 stations may connect into a single ring, with up to two kilometers between stations, provided total ring circumference does not exceed 100 kilometers. The FDDI has been slated for inclusion in GOSIP version three as a Federal Information Processing Standard (FIPS). (Minoli,1991,pp.672-680)

A typical FDDI application is shown in Figure 16. (Minoli,1991,p.678)

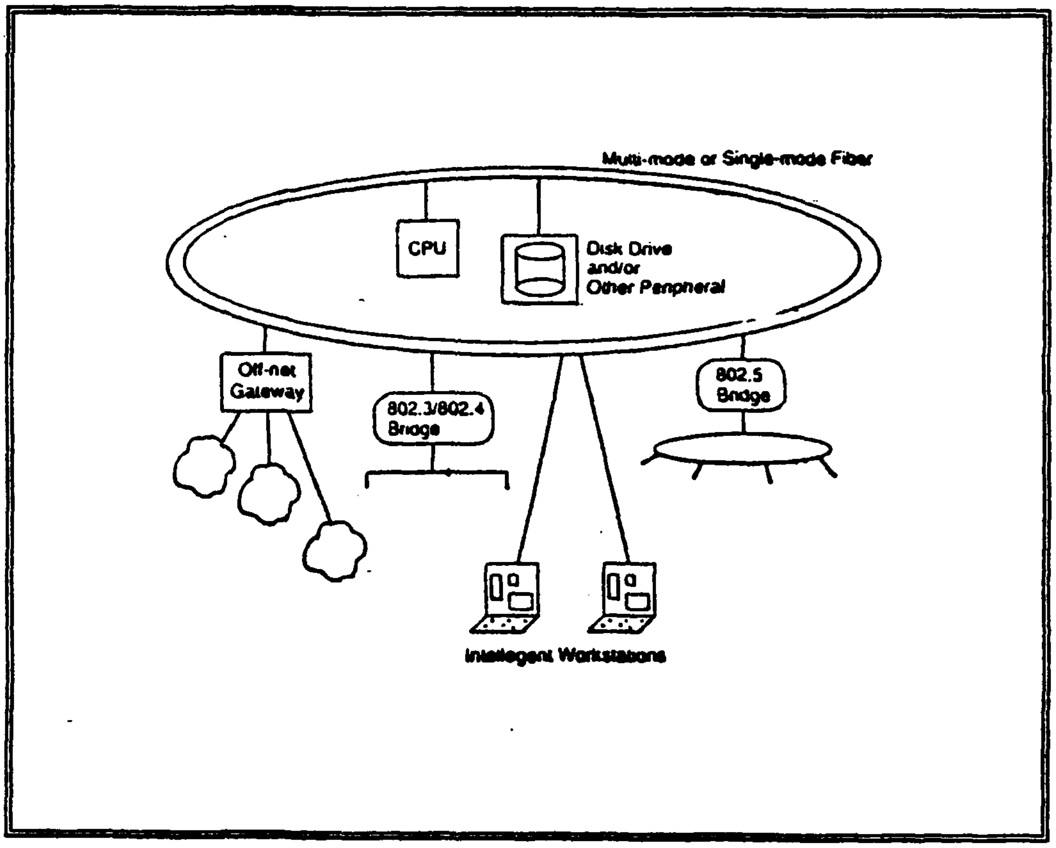

Figure 16.
A Typical FDDI Application

Another technique for MAN implementation is the recently developed Switched Multi-Megabit Data Service (SMDS). The SMDS offers customers an economical means to extend LAN performance over large metropolitan areas.

The SMDS is a connectionless, high performance, public packet-switched data service designed to interconnect computers and local area networks over a metropolitan area. Information is transferred in a short and bursty manner with speeds of 1.544 Mbps and 45 Mbps. The SMDS, sometimes used synonymously with MAN, is based on the IEEE 802.6 standard. The motivation for SMDS is based upon the need to support high-speed data exchange between geographically separated users through MAN. As such, SMDS extends the scope of FDDI, token ring, and Ethernet by allowing wide area, high performance interconnection of these networks to support high bandwidth applications. (Minoli,1991,pp.696-699)

The connectionless service offered by SMDS, which is ideal for LAN interconnection, has an advantage over current connection-oriented services. A packet of data is thrust from one piece of terminal equipment to the other. It is up to the intervening network to route the packet to the destination. Because this is a connectionless switching, as many are today, an end-to-end transport protocol must be used to provide reliability and control. This might include TCP/IP, ISO/IP or some vendor-specific proprietary protocol. Standards groups are seeking to accelerate this service.

While initial deployment of SMDS will be at speeds of 1.544 Mbps, some commercial carriers will field the service at 45 Mbps. Eventually, SMDS will operate at SONET speeds of 51.84 Mbps and up to 2.488 Gbps.

3. Wide Area Networks (WANs)

WANs permit computers to share information over long distances, even across continents. To understand how WANs function, it is useful to compare the two basic types of long-haul transmission methods: point-to-point links and "cloud" methods. Point-to-point links are typically lines leased from telephone or other communications companies. Cloud methods are switching systems that route information through networks in a way that is totally transparent to users of networks attached to the cloud. To those users, the operation of the cloud looks like a point-to-point connection even though the information may actually have traveled over several different communications lines. The most common interfaces to clouds are X.25 and frame relay, discussed in the previous chapter.

C. INTERCONNECTION METHODS AND DEVICES

To interconnect data networks, some sort of "nodal glue" is needed to join local, metropolitan, and wide area networks. The devices used to accomplish these interconnections are shown in Figure 17, and are presented in the following sections. (3Com,1991,p.7)

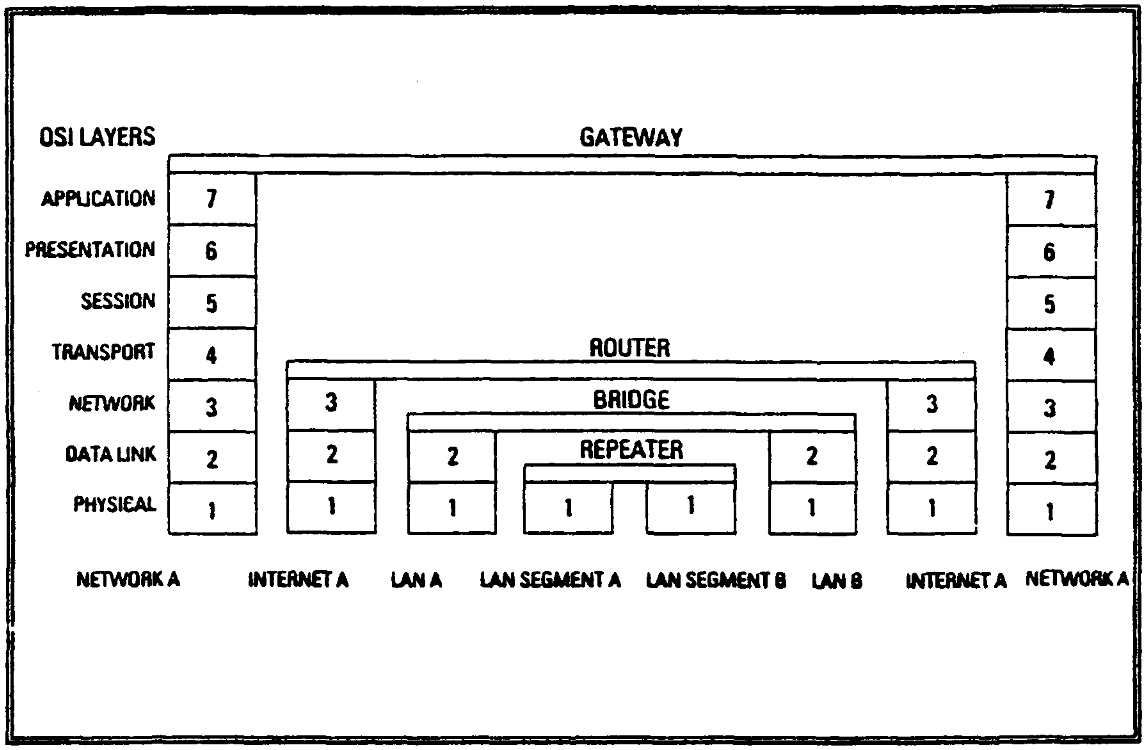

Figure 17.
The OSI Model
and Repeater, Bridge, Router
and Gateway Functionality

1. Repeaters

A repeater is a connection device that operates only at the physical layer. The repeater retimes, reshapes and reamplifies the signal received on one segment before resending it on all other segments. This regenerates and improves the signal and allows it to be sent greater distances. A repeater may be considered the digital equivalent of an amplifier. It contains a power supply and a few gates, but no logic.

2. Bridges

A bridge is a connection device used to connect two networks that use identical protocols, such as Ethernet or Token Ring. It operates at the multiple access control (MAC) sublayer of the data link layer. Bridges provide a way to join two or more networks together to form a single logical network, and they accomplish this in a way that is transparent to every device on the network. Bridges "see" the network in terms of device addresses only. They use device addresses as the basis for the decisions they make about handling packets. Information about paths, or routes, through the network is not accessible to bridges because such information is encoded in the network address, which is only accessible to a system operating at the network layer.

Thus, bridges do not make decisions about paths through the network. As a result of this limited decision-making capacity, bridges are relatively simple devices. They can provide an attractive and inexpensive way to internetwork. (3Com,1991,p.7)

3. Routers

Like bridges, routers provide users with seamless communications between physically separate networks. Unlike bridges, however, routers maintain the logical identities of each network segment. Another way of expressing this is by describing a router as a connection device that is protocol dependent, or "knows network topology." Routers "see" a network both in terms of network addresses and paths. (3Com,1991,p.7) It is a functional unit which interconnects a LAN to a WAN or MAN, or two LANs that have different MAC procedures. It operates at the network layer, connecting two networks that may or may not be similar. A router may be thought of as an intelligent device which tries to figure out the best way to get through the network. Routers often use shortest path algorithms to determine this path. Router tables are kept to specify the best way for packets to travel between nodes. Routers therefore "know" all the paths between any two points on the network, and they know which of these paths is the shortest. They may also know other characteristics of each pathway, such as its operational status, its bandwidth, or its economic cost.

Because of the additional information available to them, routers inherently can do more things than bridges can with packets. As a result, routing software is more complicated than bridging software, and is therefore more difficult to develop and implement. (Schatt,1992,p.71)

Bridges and routers are often based on the same hardware platform. Bridging and/or routing functionality is provided by the software with which these hardware systems are configured. This approach offers a great deal of flexibility to network managers. It means that the system used to create each network interconnection can be easily adapted to fit changing circumstances.

4. Gateways

A gateway is a protocol conversion device. Operating at the transport layer or above, it translates between two different peer protocols within a network. Gateways are usually considered wide area devices, with communications interfaces compatible with long-haul transmission media. They are typically associated with cloud interfaces such as X.25 and frame relay.

5. Bridging Versus Routing: How to Choose

Bridges and routers both provide a means for interconnecting individual networks into internetworks. They both provide a wide range of functionalities while helping to simplify the task of connecting networks together. However, each has its own advantages and

disadvantages, which are presented below. These are among the many factors one must consider when choosing a bridging or routing solution. (3Com,1991,pp.21-23)

Advantages of bridging include the following:

- Bridges are simple to install.
- The presence of a bridge is transparent to users from the instant it is first installed, and bridges adapt automatically to network changes.
- Bridges form logically single networks; that is, all interconnected network segments have the same network address so they facilitate movement of computers within the bridged network.
- Bridges can deliver a tremendous amount of performance at relataively modest prices, due to the underlying simplicity of bridge architecture.

Disadvantages of bridging include the following:

- Bridges cannot take simultaneous advantage of redundant paths in a network; that is, bridges cannot "load split" over network segments.
- Bridges can cause significant increases in network traffic at certain times, flooding the network. This can occur when a packet with an unknown address is sent out.
- Bridges cannot prevent "broadcast storms." A broadcast storm may occur when certain broadcast protocols cause packets to be flooded to every port.
- Bridges do not provide significant support for fault isolation or other distributed management capabilities.
- The use of bridges may prevent the use of certain applications over the network. This can occur when an application needs to use unique names on a network-wide basis. If two copies of the application are running, each under the same name, the application could malfunction and affect the performance of the whole network.
- Bridge-based internetworks may require extra attention from network administrators in order to track what is running on the network and where.

Advantages of routing include the following:

- Routers are generally more flexible than bridges. They can differentiate between paths by means of factors such as cost, line speed, and line delay, and they can be configured for equal-cost load splitting.

- Routers provide a protective fire-wall between subnetworks. This protects against broadcast storms and prevents incidents that occur within one subnet from affecting others.

- Router-based networks support any topology, and can more easily accomodate extensive network growth and complexity.

- Routers provide and can take advantage of redundant network paths, allowing them to load split certain applications to make the best use of available bandwidth.

Disadvantages of routing include the following:

- Routers are more difficult to set up and configure.

- Routers make movement of end systems between network segments more difficult. Since each segment has a different network address, moving between segments may require that the network administrator assign a new network address to the relocated end system.

- If the router is running a static routing protocol, configuring a router can be a laborious, time-consuming process.

- Some low-level protocols cannot be routed. (3Com,1991,pp.21-23)

VII. INTERNETWORKING AND INTEGRATION: TRENDS AND IMPLEMENTATIONS

The previous chapters in this thesis provided information on telecommunications networks and the devices to interconnect these networks. The premise for providing this material is the belief that innovative internetworking techniques will continue to perform essential functions as the U.S. military develops and implements its flexible response options for regional contingencies. However, the trend in telecommunications today is a pronounced movement toward integrated digital systems. This chapter describes three wide area network telecommunications services which epitomize this trend. The recent implementation of narrowband and wideband digital integrated networks illustrate how emerging technologies can provide voice, data, video and imagery services in a single network. The DoD has capitalized on these advances and is working toward implementation of a defense-wide digital integrated network. As integrated digital services become more widely available, joint warfighters are better able to achieve the interoperability goals of the C4I For The Warrior initiative.

A. INTEGRATED SERVICES DIGITAL NETWORK (ISDN)[6]

The CCITT defines the Integrated Services Digital Network (ISDN) as:

> A network evolved from the integrated digital network (IDN) that provides end-to-end digital connectivity to support a wide range of services, including voice and non-voice services, to which users have access by a limited set of standard multipurpose customer interfaces.

The concept of an ISDN began to evolve in the early 1970s to support user demands for voice, data, video, facsimile, image, graphics and text services. With the ISDN implementation, 64 kbps digital channels are provided end-to-end, from user to user. With this complete digital connectivity, all services can be integrated over the digital transmission and switching facilities. The ISDN is a complex mix of network capability and customer-premises equipment supporting a wide range of applications. It provides these services using a limited set of connection types and multipurpose user-network interface arrangements. A conceptual view of ISDN connection features is shown in Figure 18. (Stallings,1992,p.164)

[6]When referring to ISDN, we normally mean narrowband ISDN, providing DS0 (64 kbps) and DS1 (1.544 Mbps), as opposed to the higher rates possible with broadband ISDN, discussed in the next section.

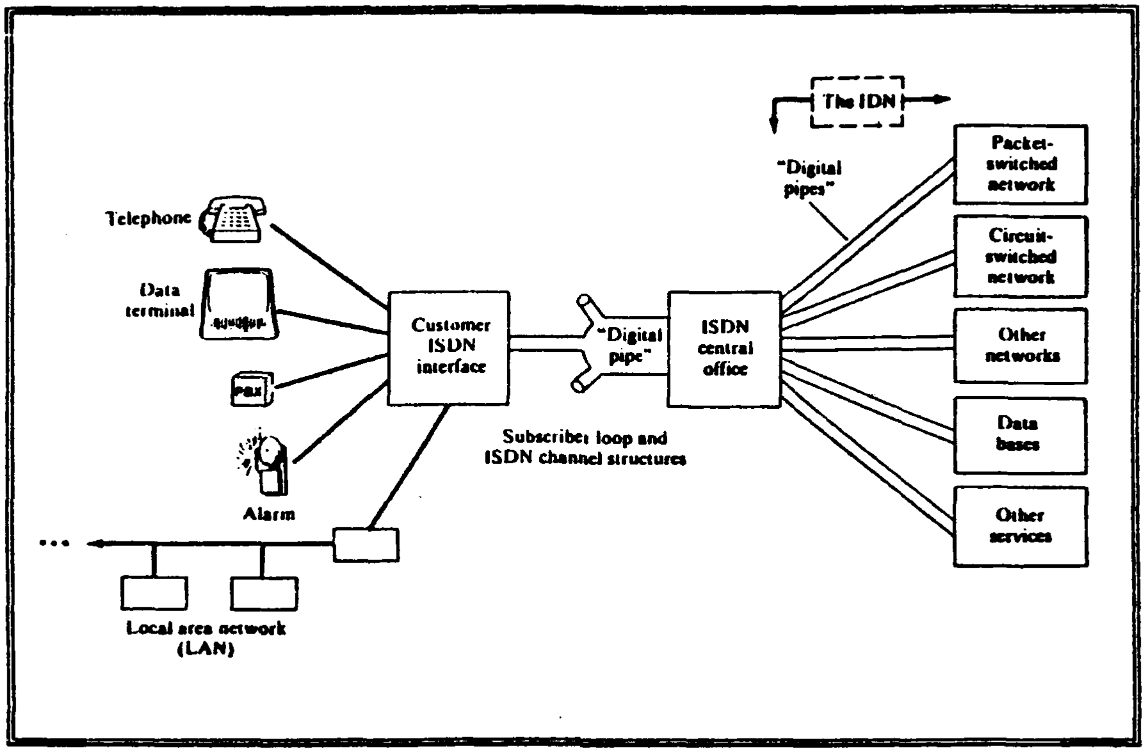

Figure 18.
A Conceptual View of ISDN

One of the challenges to ISDN implementation is developing a system which will carry the 64 kbps digital channels all the way to the customer. The local telephone network mainly consists of copper pairs to provide the final link to the customer, which are designed to carry signals up to four kHz. One solution is to substitute the copper pair by an optical fiber. However even though optical fibers are comparable in price to copper pairs, the cost involved in the changeover is prohibitive unless the demand is very significant. Copper pairs also have the advantage of being able to carry power for a telephony terminal, which is desirable for reliability and emergency situations.

Another challenge to ISDN implementation is providing an interface to the customer which is appropriate for a multiplicity of services. Data services are normally terminated in a multipin socket into which a single device can be plugged. With traditional telephone voice services, several telephones may be connected in parallel across the incoming analog line. What is needed is a system which will allow several terminals of different types (e.g., video display units, telephones, personal computers, facsimile machines) to be simply connected to the network, and a signalling system which allows the terminals to be called and make calls. (Griffiths,1992,pp.30-42)

With the multiplicity of services provided, customers may need to use more than one channel at a time. For this reason the ISDN is standardized upon a basic access which offers two 64 kbps channels, allowing the use of two terminals at a time. These channels are called B (for bearer) channels. The 64 kbps B channels are user channels designed to carry digital data, encoded digital voice, or a mixture of lower-rate traffic, including data and voice encoded at a fraction of 64 kbps. Mixed traffic must all be destined for the same endpoint. The B channel can be either circuit-switched or packet-switched, depending on user needs. The ISDN also offers a 16 kbps signalling channel, which may be used to provide access to a packet-switched service. This channel is called a D (for data) channel.

The 16 kbps D channel is always packet-switched and serves two main purposes. First, it carries signalling information to control calls on associated B channels. Second, it may be used for low speed data when no signalling information is waiting. The interface is a four-wire bus structure to which up to eight terminals can be connected in parallel.

The basic access ISDN, consisting of two B channels and one D channel, is referred to as basic rate interface (BRI). While the BRI will likely meet the needs for most residential and small business customers, large commercial firms and military users require rates in excess of 1.544 Mbps. These higher data rates are the domain of the primary rate interface (PRI) offered under broadband ISDN, discussed in the next section. Figure 19 depicts ISDN basic and primary rate interface channel structures. (Stallings,1991,p.718)

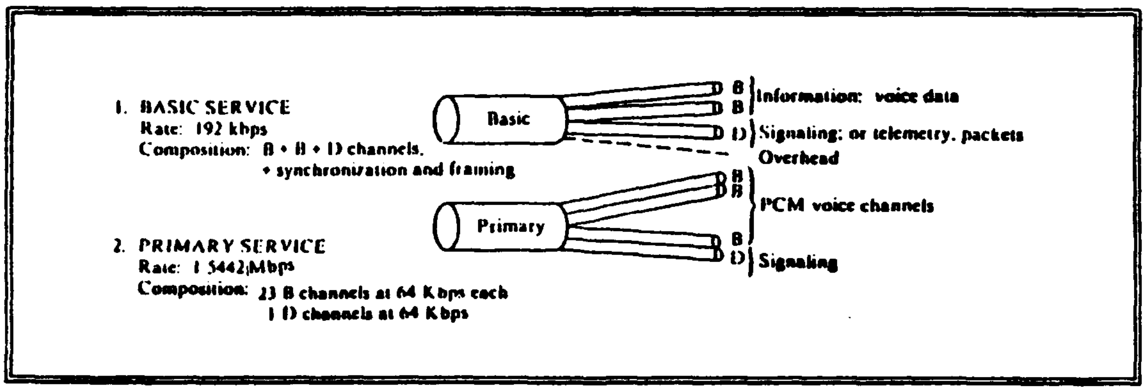

Figure 19.
ISDN Channel Structure

B. BROADBAND ISDN (B-ISDN)[7]

Broadband ISDN (B-ISDN) is envisioned as an all purpose, wide area digital network intended to support high-speed data network connectivity and video-based communication. This ATM-based network is designed to provide increased bandwidth (by orders of magnitude) beyond that of conventional narrowband ISDN. The primary motivation behind the move toward B-ISDN is the increased demand for high bit rate services, especially image and video services.

Bit-rate capabilities of B-ISDN can be considered as multiples of the 64 kbps capability of narrowband ISDN (N x 64 kbps). At the lowest end of B-ISDN comes the concatenation of several 64 kbps channels. Applications where bit rates higher than the 64 kbps offered by ISDN are needed are increasing rapidly. Video conferencing, for example, where a television size screen is needed, normally requires 384 kbps (6 x 64 kbps) or more. Reconnaissance imagery may require bit rates in the tens of megabits per second, as does high definition television. The interconnection of high-speed LANs used for computer-aided design also generates traffic at the high rates which can be accomodated by B-ISDN. Typical B-ISDN user-network interfaces are depicted in Figure 20. (Stallings,1991,p.518)

[7]Broadband (or wideband) is normally considered to have bit-rates greater than 1.544 Mbps. B-ISDN provides DS3 and SONET range digital bandwidth (optical fiber, ATM).

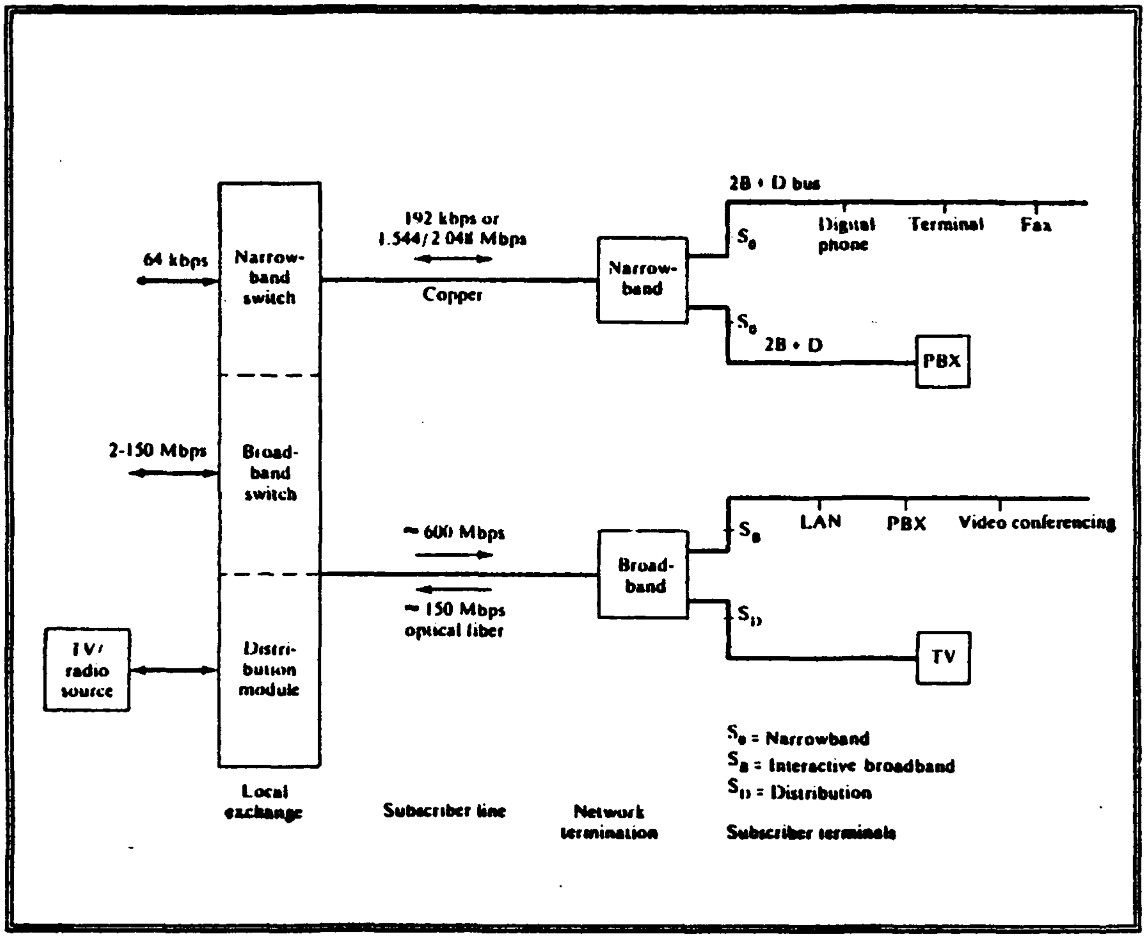

Figure 20.
Typical B-ISDN User Interfaces

There are significant improvements of B-ISDN over narrowband ISDN. They include the use of optical fiber and cell-based ATM switches. ATM has been selected as the standard switching and transmission mechanism for the B-ISDN.

A primary consideration in the move toward the higher bit-rates provided by B-ISDN is the general drift of people's expectations. The ability to handle facsimile pages in four seconds compared with the 30 seconds of the pre-ISDN era may be widely appreciated, but it may not be long before people expect the fax machine to operate at the same speed as the office photocopier, and in full color. After-action reports from Desert Storm frequently refer to commanders' desires to have more imagery of higher quality. The Defense Department's new (June 1992) Central Imagery Office is tasked to develop the ability to "provide the right imagery data to the right users in the right format at the right time. This may extend all the way down to the individual soldier in the foxhole as technology permits." (Signal,May 1993,p.57) The U.S. is a long way from having the technology to provide real-time, good-quality imagery to the foxhole soldier, but the DoD has acknowledged the need for ever-higher bit rates for future joint military operations.

C. DEFENSE INFORMATION SYSTEMS NETWORK (DISN)

Recognizing the importance of digital integrated wide area networks, the DoD has taken steps toward development of these capabilities. As described in the paper by Fu (1991), the DISN represents a move toward integration of the disparate telecommunications services now in use throughout all branches of the U.S. military. The DISN illustrates the

two aspects of telecommunications presented in this thesis--internetworking and integration. The DISN epitomizes the trend toward integration, and also confirms that internetworking will remain essential while striving to attain full integration. The DISN planners have incorporated both of these aspects into their two-phased approach to the implementation of an integrated DISN. The initial phase focuses on the consolidation of Service and Agency (S/A) long-haul communication initiatives (i.e., NAVNET, AFNET) with DISA's ongoing Pilot Internet initiative. This will be accomplished through placement and interconnecting of devices such as bridges, routers, gateways, routing bridges and "intelligent" multiplexers. The second phase proposes a broadband DISN goal architecture. This architecture will utilize the emerging B-ISDN and cell-relay (ATM) switching technologies so that voice, data, video and imagery services can be provided by a single digital integrated network.

The current Defense Communication System (DCS) is essentially viewed as a collection of independent common-user subsystems. Each subsystem was designed to provide a unique service and is riding on the common-user backbone transmission system. All the services worldwide have traditionally been supported by a subsystem infrastructure in which the primary service was to carry narrowband voice and data communications. As discussed earlier in this

chapter, increased demand for high-speed data communications and multimedia services warrant the progression of the DCS from its current limited capability to a fully integrated digital DISN.

The DISN implementation requires that common-user systems adhere to DoD-wide standards for interoperability and the sharing of assets to meet all DoD voice, data, video, and imagery communications requirements. Another requirement is that DoD initiatives must take advantage of economies of scale in the transmission tariffs to bundle all communications requirements onto one shared backbone using T1, T3 and even higher transmission speeds. The DISN concept is a key element in providing the most cost-effective way to meet DoD's evolving long-haul communications needs.

1. DISN Concept and Description

To satisfy current switched data and point-to-point circuit requirements, the near-term DISN will consist of three tiers:

- The current MILNET layer, consisting of X.25 packet switching services.
- An IP layer, providing a T1 switching capability at layer two of the OSI model.
- A smart multiplexer layer, providing T1/T3 switching capability to provide circuit bundling and full T1 service to the customers.

A typical three-layer representation of the near-term DISN is depicted in Figure 21. (Fu,1991,p.3)

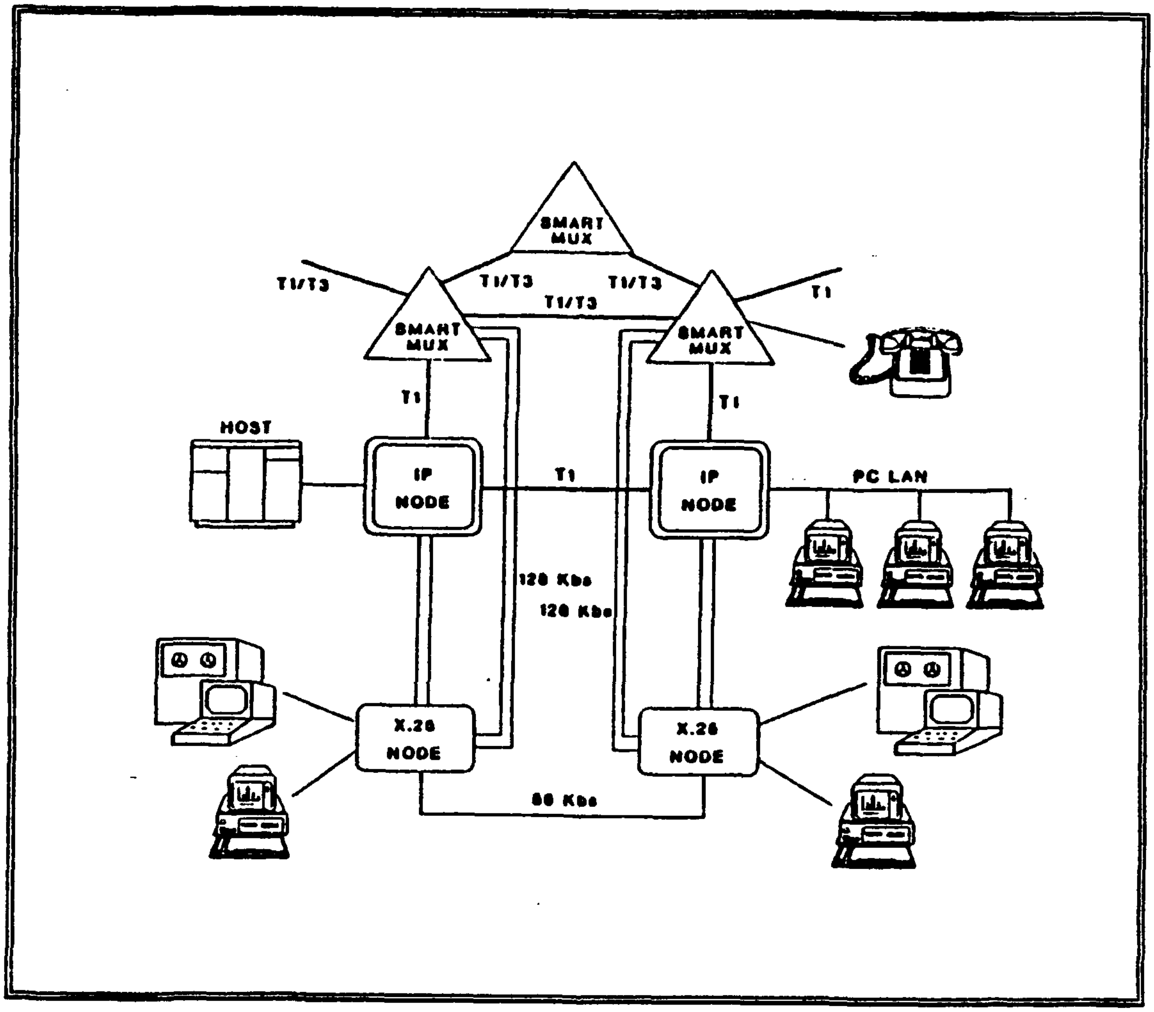

Figure 21.
DISN Near-Term Concept

The future DISN will offer users the following capabilities:

- Circuit switched voice service by providing digital transmission to transport DSN voice and data (via modems) on interswitch trunks or trunk groups from a point-of-presence (POP) on the user's facility to the designated DSN tandem voice switching center.

- Circuit switched data service by providing dial-up, full duplex, synchronous, 56 kbps (64 kbps when clear channel capability is available) from the POP on the user's facility to the DSN switching network. If the user's facility does not have a digital switching capability, dedicated digital access to the DSN can be provided.

- Packet switched service by providing a packet transport and switching service for data. This service will conform to the CCITT recommendation for the X.25 protocol, currently offered as DDN Basic X.25, while also supporting DDN Standard X.25 to the maximum extent possible. The majority of this packet switched service will be provided by the existing MILNET segment of the DDN.

- Internetwork gateway service by providing high speed gateway services delivering T1 or greater information transfer rates between networks.

- Video and audio/graphics teleconferencing service.

- Dedicated transmission service (bandwidth) by providing a dedicated transmission channel between two points.

2. Implementation Concept of the Network

Implementation of the DISN will be a two-phased approach, having different goals for each phase. In the near term (0-3 years), the Phase I DISN goal will be to migrate from the Pilot Internet and the S/A networks into an integrated, high-speed service backbone. To accomplish this, the DISN will evolve from the current Pilot Internet, expanding the IP and smart multiplexer layers of the

network. This will involve increasing the number of IP routers and smart multiplexors in the backbone, providing T1/T3 capabilities, and absorbing the S/A networks into the DISA-managed backbone. A typical consolidation at a DISN node (or base) is depicted in Figure 22. (Fu,1991,p.4)

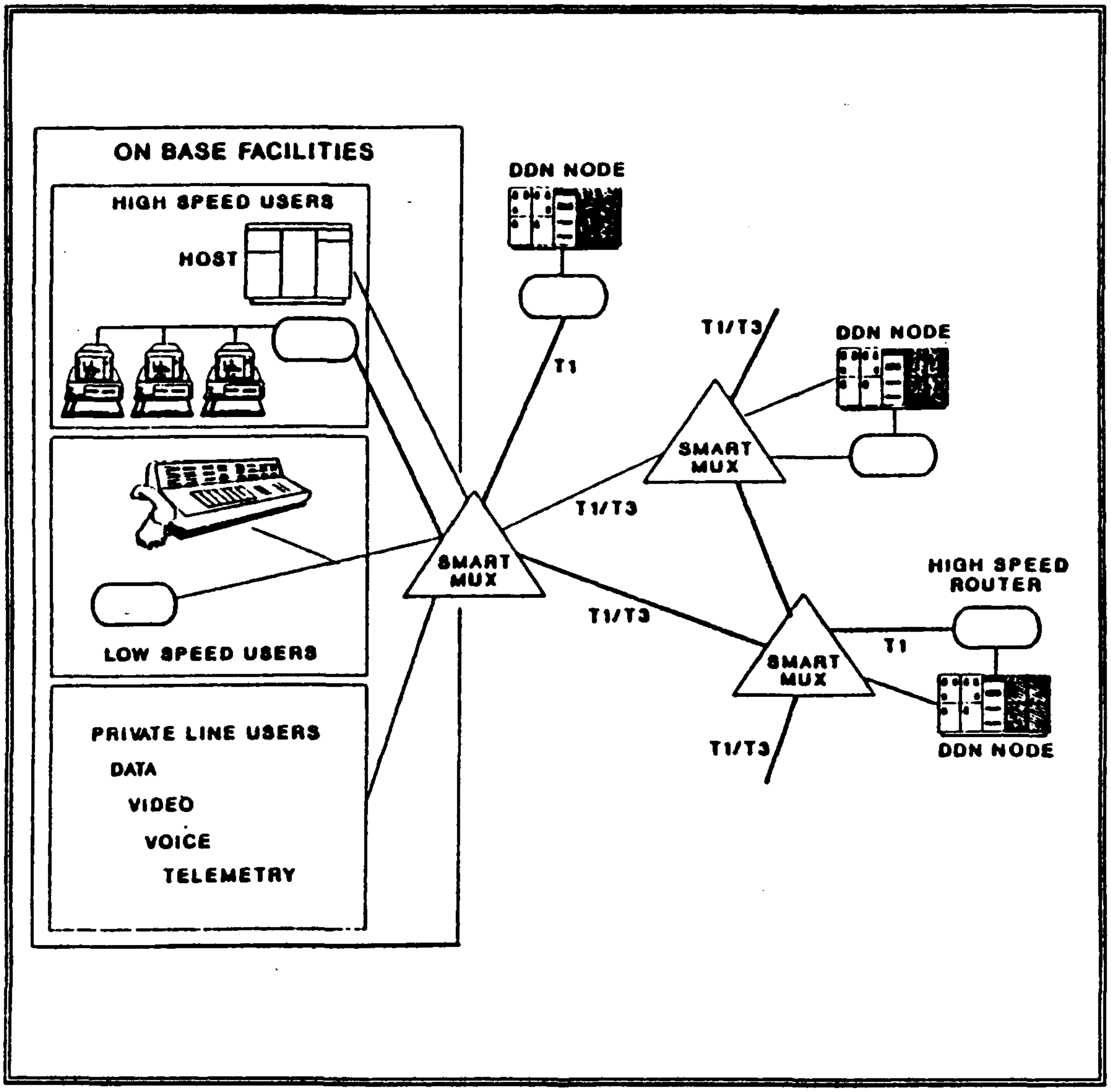

Figure 22.
DISN Near-Term Nodal Configuration

At the end of Phase I, the DISN will provide the following capabilities at each POP:

- Dedicated user capacity.
- Common-user capacity.
- Unallocated contingency capacity. This capacity is engineered into the DISN and carried as a necessary cost of operating a command and control network to ensure sufficient connectivity remains available during periods of unexpected demand or reduced capacity due to damage. This capacity will provide responsive service to short term changes in user requirements, or to route existing service demands around failed segments of the network.

3. Near-Term Solution of the Network

Specific efforts have been initiated as part of the near-term DISN. These efforts are circuit bundling, Pilot Internet expansion, and S/A network assimilation. Each is briefly described below.

- Circuit bundling: The lease cost of four to six DS0 circuits is generally equivalent to the lease cost of a T1 line, and the lease cost of eight to ten T1 lines is generally equivalent to the lease cost of a T3 line. For this reason, and due to the mature circuit-switching smart multiplexer technology and network management development, cost savings is possible through bulk leasing. Individual leased circuits can therefore normally be bundled to achieve improved service and cost savings.
- Pilot Internet Expansion: Each pilot internet node, at ten sites throughout the U.S., consists of a MILNET packet switch node (PSN), a circuit switch, and a IP packet switch. The Pilot Internet will be expanded to accomodate traffic currently on existing S/A networks and upgraded to optimize the near-term DISN topology and access lines.

- S/A networks assimilation: As the Services and Agencies continue to pursue their separate "stovepipe" high-speed networking initiatives, the number of independent S/A networks is constantly growing. Unless these networks are implemented by the same equipment, these networks will most likely not be able to talk to each other. This is expected to change as networking standards evolve. The situation today is depicted in Figure 23. (Fu,1991,p.5)

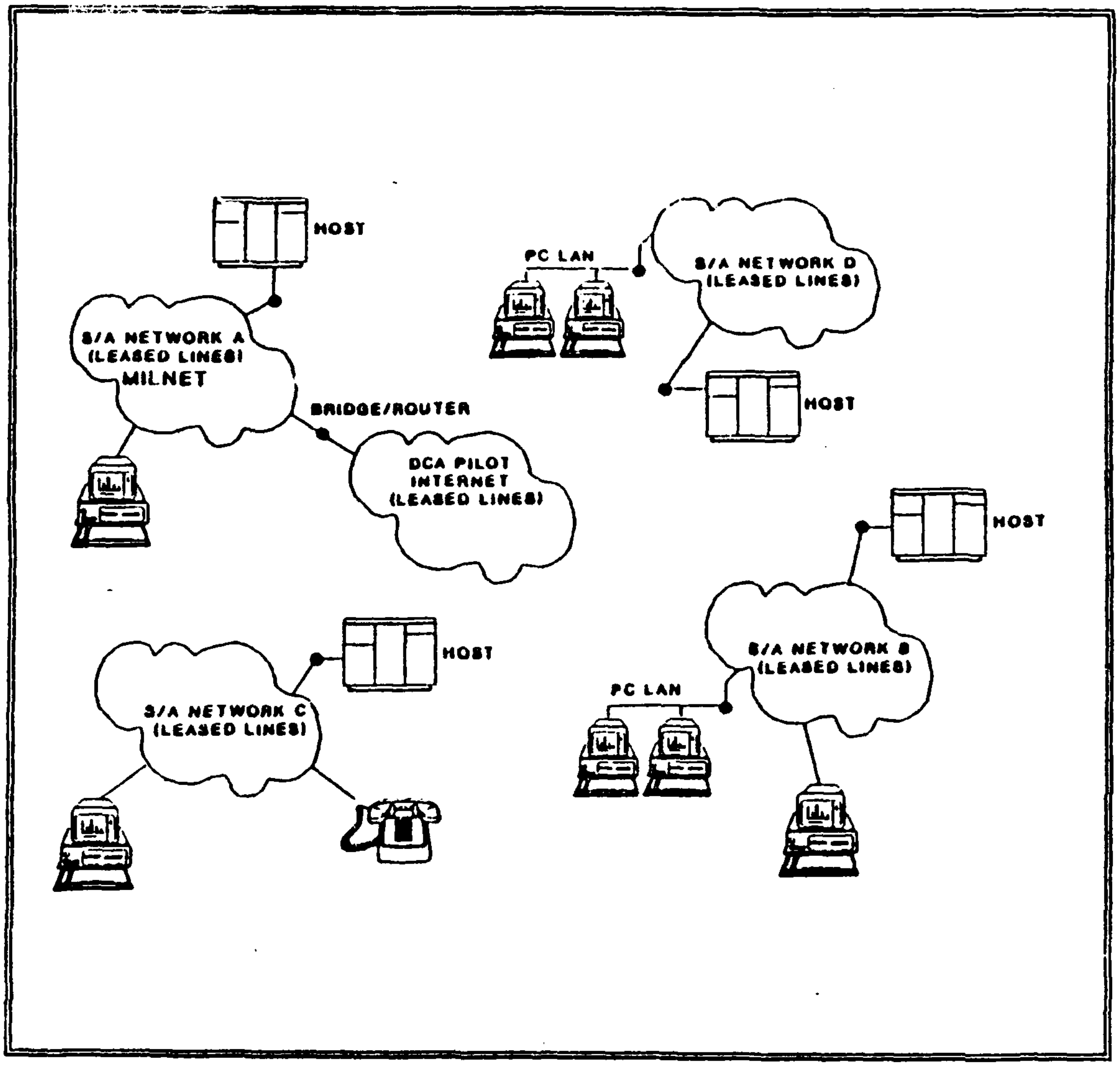

Figure 23.
DISN Today

To implement the near-term DISN there are two possible approaches: internetworking and full integration. Internetworking is to let the Pilot Internet grow, not by accretion, but by the coalescence of heterogeneous S/A networks.

Interoperability through internetworking can be achieved by use of devices such as bridges, routers, gateways, and routing bridges. Since the circuits within each network were separately leased these circuits will be bundled with circuits in the Pilot Internet and other networks through smart multiplexers.

On the other hand, full integration is based on total traffic requirements, facility locations, and performance specifications to determine the most cost-effective DISN topology, size, and hardware/software specifications. This approach accomplishes the following:

- Standardizes the equipment, i.e., same equipment will be installed at every DISN node.
- Optimizes network topology, backbone size and access circuits.

These two approaches result in two different networks which are conceptually depicted in Figures 24 and 25. (Fu,1991,p.6)

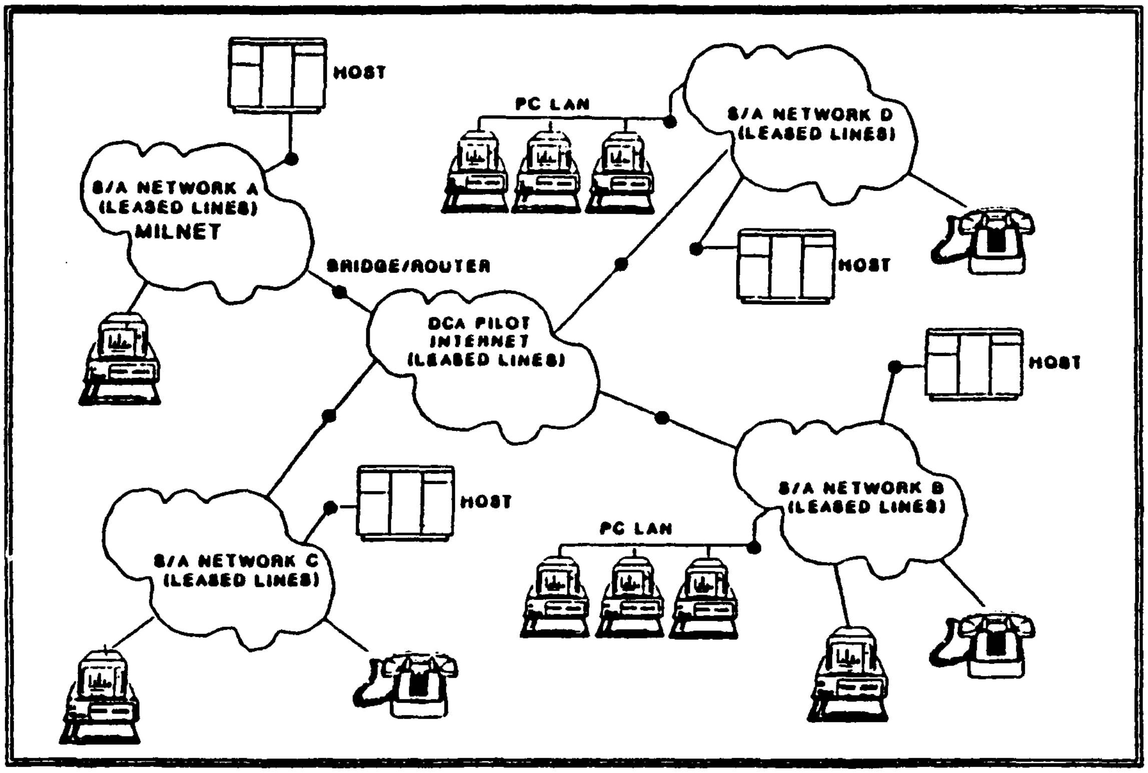

Figure 24.
DISN Near-Term (Internetworking and Circuit Bundling)

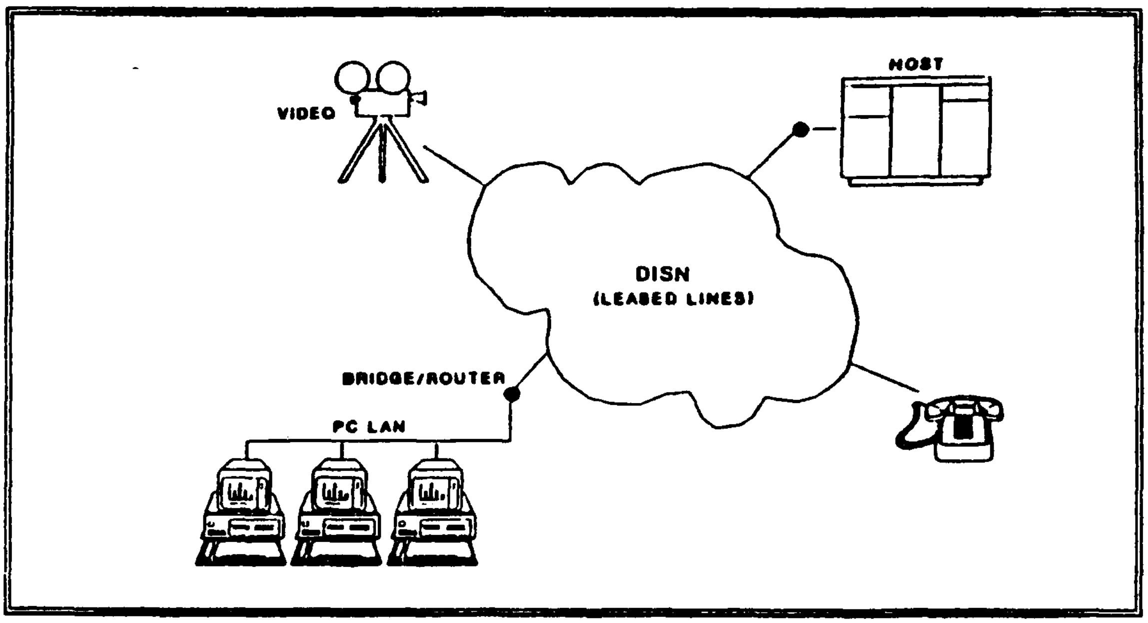

Figure 25.
DISN Near-Term (Full Integration)

The full integration approach normally takes longer and more resources than the internetworking approach. Cost, risk and network size are the basic factors in determining which approach should be taken. It is envisioned that the internetworking approach is suitable for consolidation of existing networks, while the full integration approach is envisioned for the far-term DISN pending industry and technology evolution.

The goal of far-term DISN is to allow technology insertion and to move to the increasing use of open-system standardized networks, which have fewer DoD-unique features and vendor-proprietary designs and are procured in a more competitive environment. As B-ISDN and cell-relay ATM multimedia service will be offered by commercial carriers during the mid-to-late 1990s, a far-term DISN architecture is proposed, as depicted in Figure 26. (Fu,1991,p.6) This proposed broadband architecture is designed to support a wide variety of network services and a broad range of access rates up to 150 Mbps.

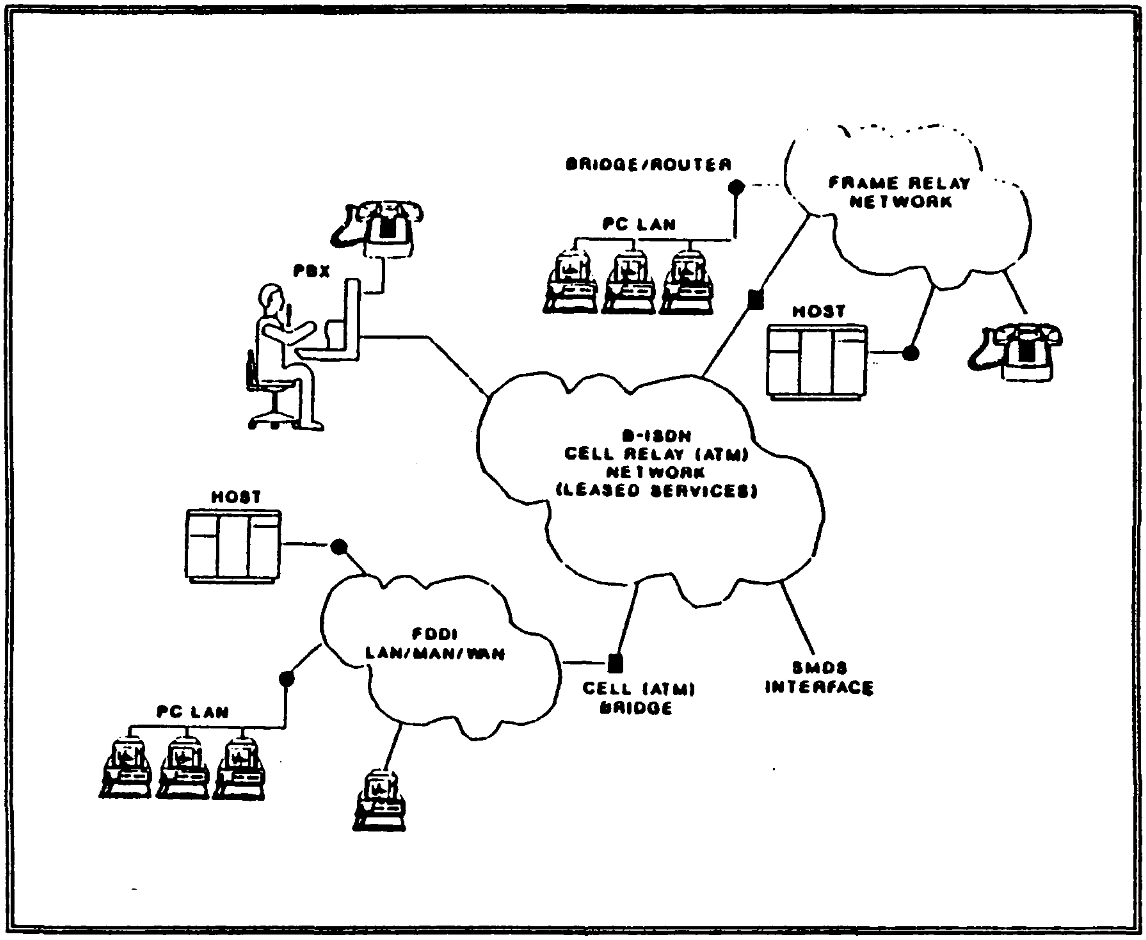

Figure 26.
DISN Far-Term (Goal Architecture)

As time moves toward the 21st Century, DISN will take advantage of emerging technologies, such as B-ISDN and cell relay (ATM) switching, to migrate from a collection of independently connected S/A networks into a truly integrated DISN. This DISN will then be capable of meeting all integrated voice, data, video and imagery service requirements of the DoD.

VIII. SUMMARY

This thesis has presented an introduction to telecommunications internetworking and integration in support of warfighters' needs. This topic is particularly relevant in today's changing political and military environment, where implementation of flexible response options demands increasingly more and faster voice, data and imagery connectivity.

Commanders' wishes to send anything, anytime, anywhere can often be met with today's greater bandwidths, and integration of information services on a unified infrastructure. Particularly significant advances have been made in switching and transmission techniques, providing high data rates. In fact, some sources feel that these switching and transmission advances have outpaced the capabilities of terminals and applications to take advantage of the improved services provided. The technical capabilities for virtually unlimited bandwidth have spawned increasing demands for support, such as that of real-time imagery to the foxhole.

The interconnection of various data networks, explained in this thesis, is a critical element in ensuring that commanders' information needs are satisfied. The discussion of how to choose between bridges and routers is provided to

help military C3 professionals determine how to interconnect individual networks into internetworks. This interconnection process is a step toward the overall goal of consolidation of voice, data and imagery into fully integrated digital wide area networks.

The international and U.S. standards-making bodies are attempting to keep up with the fast-paced evolution of the telecommunications field. These standards-making bodies establish a framework of open standards, within which vendors can competitively develop and implement new products and techniques. The U.S. military can also benefit from these open standards by, whenever possible, adapting the innovative developments of industry. Making widespread use of industry's advances for military applications is in harmony with the move away from military "stovepipe" systems, as is articulated in the C4I for the warrior initiative.

The DISN concept, discussed in the previous chapter, is the DISA's vision for the future DoD communications backbone. The DISN incorporates recent technological advances into a framework for satisfying evolving U.S. military connectivity needs. As such, it appropriately illustrates the material presented in earlier sections of this thesis.

To anticipate and fulfill evolving U.S. military telecommunications needs, future C3 planners and operational

staff members require an understanding of the fundamentals provided in this thesis. This understanding of internetworking and integration techniques and principles can help ensure that they are able to take best advantage of rapidly evolving telecommunications technologies. Military C3 professionals need to continue to look ahead. They must carefully track developments in the telecommunications industry, and attempt to adapt open systems COTS equipment for military implementations wherever practical. By doing so, they will be helping the U.S. military maintain its world-wide technological edge, a vital element for ensuring overall warfighting superiority.

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